FOREIGN-BORN SCIENTISTS IN THE UNITED STATES –DO THEY PERFORM DIFFERENTLY THAN NATIVE-BORN SCIENTISTS?

A Dissertation
Presented to
The Academic Faculty

By

Sooho Lee

In Partial Fulfillment
Of the Requirements for the Degree
Doctor of Philosophy in the
School of Public Policy

Georgia Institute of Technology

November, 2004

FOREIGN-BORN SCIENTISTS IN THE UNITED STATES –DO THEY PERFORM DIFFERENTLY THAN NATIVE-BORN SCIENTISTS?

Approved by:

Dr. Barry Bozeman (Chair)
School of Public Policy

Dr. Juan Rogers
School of Public Policy

Dr. Monica Gaughan
School of Public Policy

Dr. Paula Stephan
Department of Economics,
Georgia State University

Date Approved: November 2004

ACKNOWLEDGMENTS

First of all, I thank my gracious, rigorous and generous advisor, Professor Barry Bozeman, for his constant care, patience, and support as he guided me through my studies at Georgia Tech. Through him, I have learned a great researcher's curiosity, tireless enthusiasm, integrity, and persistence – characteristics that I also want for my life. I also thank Professor Juan Rogers and Professor Monica Gaughan for their invaluable suggestions and constant encouragement not only for the content and effort that went into this dissertation but also for my studies and life in Atlanta. I especially thank Professor Paula Stephan for her insightful comments and important reading materials. Her works guided me in many places in the dissertation. I also thank Professor Gordon Kingsley for his interest in my research and his support.

Appreciation is also expressed to the Research Value Mapping (RVM) Program at Georgia Tech in which I have deepened my knowledge of science and technology policy. Through the RVM, I was privileged to use the data of the research projects that National Science Foundation (NSF) and Department of Energy (DOE) sponsored. I want to thank all the members of the RVM for their contributions to data collection, collaboration in the research, and for our friendships.

I also thank my two sons, Albert (Hyunwoong) and Chris (Hyunchan), for their smiles and faith in me. My parents, my mother-in law, my sisters, and my relatives have been a constant source of support through their love and prayers. But my greatest thanks and appreciation go to my wife, Mi Ja, for her love and constant encouragement. Without her support and understanding, completion of my studies would have been impossible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AAUP	American Association of University Professors
CV	Curriculum Vitae
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
ERCs	Engineering Research Centers
FBFB	Foreign-born scientists who earned their bachelor's degree outside the U.S.
FBFB0	FBFB who came from the least advantageous, neither western culture nor English-spoken
FBFB1	FBFB who came from the less advantageous, either western culture or English-spoken
FBFB2	FBFB who came from the most advantageous, western culture and English-spoken
FC	Fractional count of publications
I/UCRCs	Industry/University Cooperative Research Centers
NAFSA	Association of International Educators
NAS	National Academy of Sciences
NAE	National Academy of Engineering
NC	Normal count of publications
NRC	National Research Council
NSB	National Science Board
NSF	U.S. National Science Foundation
R&D	Research and Development
RVM	Research Value Mapping Program
S&T	Science and Technology
SEM	Structural Equation Modeling
S/IUCRCs	State/Industry Cooperative Research Centers
STC	Science and Technology Center

SUMMARY

Are foreign-born scientists different from native-born scientists with respect to research activity and performance? This question has important policy implications not only for immigration policy but also for science policy because a substantial part of scientific research in the United States is conducted by foreign-born scientists. This study examines the differences between foreign-born and native-born scientists in research collaboration, grants, and publication productivity. The data for this study are 443 curricula vitae (CVs) and survey of scientists and engineers that Research Value Mapping Program (RVM) at Georgia Tech conducted from 2000 to 2001.

By using the multiple indicators, the findings show that foreign-born scientists do not differ significantly in research collaboration and grants from their native-born counterparts. But in terms of publication productivity, foreign-born scientists are consistently more productive than their native-born counterparts. This study also examines the impact of being foreign-born on research collaboration, grants, and productivity, and which factors account for the differences between foreign-born and native-born scientists in collaboration, grants, and productivity. When other relevant variables are controlled for, being foreign-born still has a strong positive effect on publication productivity. Collaboration and grants have a significant positive effect only on the productivity of native-born scientists, whereas strong research preference of foreign-born scientists contributes to their relatively higher productivity. Differences are also found among foreign-born scientists, largely depending on their national origin categorized by the similarity of language and culture. The theoretical and policy implications are also discussed.

CHAPTER 1

INTRODUCTION

1.1 Research motivation

This study is motivated by the growing importance of foreign-born scientists in the United States and the relative lack of information on foreign-born scientists' research activity and performance. The most recent National Science Foundation data (*Science and Engineering Indicator 2004*) show that a large proportion of the science and engineering workforce in the United States is made up of foreign-born scientists and engineers. In 2000, foreign-born scientists and engineers accounted for 37.6 percent of the doctorates in science and engineering occupations (Table 1), and for 20.9 percent of the science and engineering faculty in U.S. universities (Table 2). In the categories of natural sciences and engineering, about 30 percent of university faculty are foreign-born. Specifically, among engineering faculty, 35.5 percent are foreign-born. Between 1973 and 1999, academic employment of foreign-born doctoral scientists in the United States increased by more than four times, from 13,531 to 73,268. Among them, almost 33 percent are foreign-born and foreign Ph.D.s (NSB, 2002).[1] This employment of foreign-born scientists in the United States seems likely to continue to increase because fewer U.S. bachelor of science graduates are choosing to enter science and engineering graduate schools (Seymour and Hewitt, 1997; National Science Board, 2003) and the

[1] NSF data on foreign-born, foreign-earned Ph.Ds are unavailable for 1973-1992. In 1993, the number of foreign-born U.S. Ph.Ds was 40,473 and 21,589 for foreign-born, foreign Ph.Ds. In 1999, in U.S. universities and colleges foreign-born U.S. Ph.Ds numbered 49,011 and foreign-born, foreign Ph.Ds stood at 24,257. The number of foreign-born scientists who earned their doctorate outside the United States has steadily increased (NSF Indicators 2002, p5-25).

stay rate[2] of foreign students is increasing – for example, from 50 percent in 1985 to 76.4 percent between 1998 and 2001 (NSB, 2004).

Despite the ever-increasing number of foreign-born scientists, studies of foreign-born scientists' research activity and performance rarely have been conducted and is often termed an "understudied topic" (Manrique & Manrique, 1999; Mervis, 2004). This lack of knowledge may represent a serious gap between immigration and science policy and practices in academic research institutions. The primary objective of this research is to provide the policy community with empirical evidence of foreign-born scientists' research activity and performance and to enhance the theoretical understanding of the role of foreign-born scientists in academic research.

Table 1. Foreign-born scientists and engineers in U.S. S&E occupations, by degree level: 1990 and 2000

Degree	1990	2000
All college degrees	14.13 %	22.40 %
Bachelor's	10.59 %	16.50 %
Master's	18.86 %	29.00 %
Professional	24.06 %	35.80 %
Doctoral	23.69 %	37.60 %

NOTE: Data exclude postsecondary teachers because the field of instruction was not included in occupation coding for the 2000 census.
SOURCE: *Science & Engineering Indicators – 2004*

[2] NSF's Survey of Earned Doctorate (SED) asks foreign doctoral recipients if they have a plan to stay or a firm plan to stay in the United States. Among 18,113 S&E doctoral recipients in 1985, 50 percent had a plan to stay, and 40.1 percent had a firm plan to stay. Among 36,878 recipients of S&E doctoral degrees between 1998 and 2001, 76.4 percent had a plan to stay, and 54.1 percent had a firm plan to stay (NSF Indicators 2004). In the meantime, Michael Finn (2003) of the Oak Ridge Institute for Science and Education found that 56 percent of 1996 U.S. S&E doctoral degree recipients with temporary visas remained in the United States in 2001. The number of foreign students staying after obtaining their doctorates implies that approximately 3,500 foreign students remain from each annual cohort of new S&E doctorates in all fields. Stay rates differ by field of degree, ranging from only 26 percent in economics to 70 percent in computer and electrical engineering.

Table 2. Foreign-born share of S&E doctoral faculty, postdocs, and graduate students, by major degree field: 2001

Field	Faculty	Postdocs	Graduate students
All S&E fields	20.97 %	57.23 %	33.74 %
Physical sciences	22.87 %	67.16 %	41.47 %
Earth, atmospheric, and ocean sciences	17.12 %	42.13 %	23.33 %
Mathematics	28.07 %	56.50 %	46.39 %
Computer sciences	38.65 %	61.77 %	65.53 %
Life sciences	19.97 %	55.70 %	17.31 %
Psychology	7.81 %	25.90 %	5.83 %
Social sciences	18.79 %	31.07 %	27.21 %
Engineering	35.49 %	68.95 %	58.03 %

NOTE: Because the data includes only U.S. doctorate holders, the foreign-born share is understated.
SOURCES: *Science & Engineering Indicators – 2004*

1.2 Background and policy context

The increasing proportion of foreign-born scientists has prompted important policy debates about foreign scientific labor. The theme most often addressed is: Should the United States be more open (Shusterman, 1991; Saxenian, 1999; Glanz, 2003) or more closed (Matloff, 1997, 2002; Bryant, 2002) to foreign-born scientists? Although there has been a tradition of "accepting the status quo without too much thought" in recruiting foreign-born students and scientists (Goodwin and Nacht, 1983), decision-making on immigration policy for the scientific workforce has relied largely on the labor market[3] that eventually reflects the U.S. domestic supply and demand for scientists (Atkinson, 1990; Martin, 2003). During the Silicon Valley boom era, many foreign

[3] Although the labor market is important in deciding who can work in the United States, political reasons sometimes are decisive. For example, the Chinese Student Protection Act of 1992 granted almost 25,000 Chinese students and scientists permanent residency. The stated purpose of the act was to prevent political persecution of Chinese students in the aftermath of the Tiananmen protests of 1989.

scientists came to the United States through the increased quota for H-1b visas, a main passage for foreign skilled labor, but the idea of limiting the quota has attracted much attention from policymakers just after the economic downturn began early in the 21st century (Henry, 2002).

The debate about *open versus closed* is deeply related to the perspective of whether such immigration is, on the whole, good or bad for the country. Both sides cite benefits and costs that foreign-born scientists may bring to the United States. First, one of the primary benefits[4] that are often cited is that foreign-born scientists disproportionately contribute to the knowledge production of U.S. science (Lerner and Roy, 1984; Levin and Stephan, 1999; Stephan and Levin, 2001). Stephan and Levin (2001)[5], the most cited work in this vein, evaluated foreign-born scientists' contributions by using six criteria.[6] They found that 19.2 % of the National Academy of Engineering (NAE) group and 23.8% of the National Academy of Sciences (NAS) group was foreign-

---

[4] In relation to foreign students, the proponents of openness also point out some other benefits: (1) Foreign policy benefits: By hosting international students, the United States can generate an appreciation of American political values and institutions and lay the foundation for constructive relations based on mutual understanding and goodwill. The ties formed at school between future American and future foreign leaders have facilitated innumerable foreign policy relationships. There is a remarkable reservoir of goodwill for the United States that is perhaps the most undervalued foreign policy asset. (2) Economic benefits: The Association of International Educators (NAFSA) estimates that international students and their dependents spent nearly $12 billion in the U.S. economy in 2002, which makes international education a significant U.S. service-sector export. More than 70 percent of undergraduate international students pay full tuition and receive no financial aid, thus allowing schools to offer more financial assistance to American students. (3) Educational benefits: International students enrich American higher education and culture. For American students, college or university life provides their first close and extensive contacts with foreigners. These contacts begin the process of preparing these students to be effective global citizens. They make important contribution to scientific research and their enrollment in under-enrolled science courses often is decisive for a school's ability to offer those courses. In some ways, graduate education could not function without international students (NAFSA, 2003)

[5] This study included 1,554 members of the National Academy of Sciences (NAS) and 1,706 members of the National Academy of Engineering (NAE). It used ISI data for citation counts and chose 138 papers, declared classics by ISI during the period June 1992 to June 1993 in the areas of life sciences (agriculture, biology, and environmental sciences), physical, chemical and earth sciences, and clinical medicine and engineering. The benchmark year was 1980 for the data.

[6] Individuals elected to the National Academy of Sciences (NAS) and/or National Academy of Engineering (NAE), authors of citation classics, authors of hot papers, the 250 most-cited authors, authors of highly cited patents, and scientists who have played a key role in launching biotechnology firms.

born, while only 13.9% of the engineers and 18.3% of the scientists in the scientific labor force as of 1980 were foreign-born. In the life sciences, 29.1% of the most cited authors, 27.5% of citation classics, and 17.8% of the hot papers are foreign-born, compared to a population percentage of 15.4. In the physical sciences, 64.7 % of the most cited authors, 40.9% of citation classics, and 35.5% of hot papers are foreign-born, compared to 20.4% of physical scientists in the U.S. scientific labor force as of 1980. Based on the results, they concluded that foreign-born scientists disproportionately make exceptional contributions to U.S. science and that the United States has benefited from the inflow of foreign-born scientists.

A second benefit that is often cited in terms of economic impact is that foreign-born scientists may spur scientific innovation and increase U.S. competitiveness (National Academy of Engineering, 1996). As clearly stipulated in the Immigration Act of 1990 and the American Competitiveness and Workforce Improvement Act of 1998, skilled foreign workers are expected to promote cross-fertilization that improves the competitiveness of U.S. firms. It is well-known that the tremendous growth of U.S. information technology (IT) industry during the 1990s was supported by a large influx of foreign engineers, particularly in the high technology industry of Silicon Valley and the Route 128 area (Saxennian, 2002).

Third, another often cited benefit is that foreign-born scientists provide cheap labor for the high technology industry and for temporary jobs (e.g., postdoctoral positions) in academic research (Mervis, 1999; Saxenian, 1999; NSB, 2004). Although empirical data are not readily available in comparing wage differences between foreign non-immigration visa holders (e.g., a H1-b visa or other temporary visa) and native-born scientists, it is generally assumed that U.S. companies benefit from cheap foreign skilled labor (Saxenian, 1999).[7] Particularly in academic research, foreign postdoctoral researchers perform a crucial role in research. They account for 57.23 % of postdoctoral positions in U.S. academic institutions (NSB, 2004).[8] Postdoctoral researchers perform a substantial fraction of skilled work in research labs and are responsible for a disproportionate share of new discoveries. A 1999 study found that 43 % of first authors of research articles in *Science* were postdoctoral researchers (Vogel, 1999).

Lastly, "brain gain" – the migration of foreign talent into the United States – is another benefit, according to proponents of their entry. They argue that the growth of human capital improves U.S. productivity and contributes to U.S. scientific and industrial innovation (Grubel and Scott, 1966; Johnson and Regets, 1998; Skolnikoff, 1993; Holmstrom et al., 1997). In recent U.S. history, foreign talent performed vital roles in several important scientific missions (e.g., Manhattan project, NASA space programs).

Counter arguments for an open-door policy are based on costs and risks that foreign scientists may bring to the U.S. scientific labor market and education. Fear that the large number of foreign-born scientists may make the job market more competitive and take jobs from native-born scientists has been a primary argument. The National Research Council's *Foreign and Foreign-born Engineers in the United States: Infusing Talent, Raising Issues* was one of the first major efforts to address the issue. By using the 1982 NSF Postcensal Survey as the main data source, this study found that native-born scientists' competition with foreign scientists may reduce their wages and diminish their

[7] However, some studies report that foreign-born scientists earn similar or higher wages than U.S.-born scientists for comparable work (Finn, 1988; North, 1995). According to North, naturalized foreign-born scientists usually earn more than their native-born counterparts (North, 1995, p106-110)
[8] The data include only U.S. doctorate holders; the foreign-born share is understated.

access to graduate training and job opportunities, raising concern[9] for the future of the U.S. scientific workforce. In a recent study of this displacement problem, Stephan and Levin (2003) found that although it is not clear whether displaced citizens were pushed out by the heavy inflow of foreign talent or pulled out by the lure of better opportunities elsewhere in the economy, citizen scientists have been displaced from academe by their non-citizen counterparts, and the displacement of native-born scientists is largest in mathematics and in computer science.

Second, and closely related to the first argument, is a concern that the large presence of foreign-born scientists may bring down native-born scientists' wages and reduce their access to graduate training and job opportunities. A study found that a 10 percent immigration-induced increase in the supply of doctorates lowers the wage of competing workers by about 3 to 4 percent (Borjas, 2004). Low wages and limited opportunity in turn may discourage future generations of domestic talent from pursuing science and engineering careers, particularly, at the doctoral level (National Research Council, 1988; Bouvier and Somcox, 1994; Borjas, 1994; North, 1995; Anderson, 1996; Fechter and Teitelbaum, 1997; Stephan and Levin, 2003). In 1995, David North dealt with the issue of why fewer Americans are going into S&T fields. In his book, *Soothing the Establishment: The Impact of Foreign-Born Scientists and Engineers on America,* he found that the relatively slow growth in the number of Americans choosing S&T careers is in part the result of a poor earnings potential in comparison with other professions

[9] One concern is that while the proportion of foreign-born scientists increases rapidly, that of minority scientists (especially African-American) decreases even in historically black universities and colleges (Rodriquez, 1998)

such as law, medicine, and business. Foreign scientists are mostly centered in S&T fields, particularly in science and engineering.

Third, some argue that foreign-born scientists, on average, are not contributing much to U.S. science (Matloff, 1997). Matloff argued in his testimony before the U.S. Congress that the vast majority of major technical advances made in computer science and engineering have been made by U.S. natives, not by immigrants.

Finally, foreign-born scientists may pose a national security risk, in the sense that they could use the knowledge that they have learned to harm the United States and its allies (National Academy of Engineering, 1996; Bryant, 2002; Stephan and Levin, 2002; Greenwood and Riordan, 2002).

In addition to the debate of costs and benefits, what has made the issue of foreign-born scientists more salient is the U.S. political atmosphere since the September 11 attacks. As with other immigration-related issues, foreign-born scientists, particularly those who recently immigrated to the United States, face a seemingly stringent attitude from U.S. policies. Immigration to the United States involves stricter screening than it did previously (Nakashima and Sipress, 2002), which often causes visa delays and complaints among foreign scientists (Choi, 2004). The new visa policy seems responsible for the recent decline in the number of foreign student applications to U.S. graduate schools (Arnone, 2004).[10] Not only is entry a concern for policymakers, but so, too, is the restriction of foreign-born scientists to research projects that will not compromise national security. In a notable case, one MIT professor canceled his ongoing

[10] Arnone (2004) reported that more than 90 percent of American colleges and universities have seen a drop in applications from international graduate students for the fall 2004 term, and the number of submissions has fallen 32 percent from last year.

contract with the Department of Defense (DOD) because new security regulations after the September 11 terrorist attack prohibit the participation of international researchers (Rosenwald, 2003). As the American Association of University Professors (AAUP) recently revealed (2003), the academic community is now struggling with balancing academic freedom and national security.

However, the restriction issue is not the only significant change since September 11; another is the increased interest in assessing the role of foreign scientists working in the United States. Among academic scientists, this attention has meant a more detailed focus on the research activity and performance of foreign-born scientists (Mervis, 2004). Although the future of U.S. scientific labor may be the major concern in the policy debate, it seems very important to inquire about the differences between foreign-born scientists and equivalent domestic scientists (Fechter and Teitelbaum, 2002). In a recent special section of *Science* (28 May 2004), Mervis argues that “policymakers abhor a vacuum” in which policies are largely based on anecdotal evidences and lack valid analysis of foreign-born scientists’ research activity, environment, resources, and performance.

1.3 Research question and significances

This study examines whether foreign-born scientists in academic institutions differ in research activity and performance from their native-born counterparts and why and how they differ (or do not differ). This study is significant for two important reasons. Within the context of policy, information on the research activity and performance of foreign-born scientists may help the formulation of immigration and science policy. Very little is known about how foreign-born scientists engage in research activity differently, if they do, and what factors determine their research activity and performance. There is a need to address the question of whether scientists in the United States, regardless of their national origin, are homogenous in their style, strategy, level of research activity and performance. So far policy studies of science and technology have focused more on gender and ethnic differences than on whether or not a scientist is foreign-born. As long as research is affected not solely by universalistic norms (Merton, 1973) but also by particularism (Cole and Cole, 1973) and social factors (Hess, 1995; Hara, 2003), the background of national origin needs to be seriously examined in the study of research activity and performance. With such a large proportion of foreign-born scientists residing and working in the United States, the study of differences between foreign-born scientists and native-born scientists provides a meaningful basis for both policy and theory.

As its second important contribution, this study also will enrich the understanding in the United States of foreign-born scientists, serving to balance previous research in other contexts. Economists have often dealt with income differences between immigrants and native-born counterparts (Chiswick, 1978; Borjas, 1994; Dustmann, 2002), human capital mobility (Wermuth and Wermuth, 1975; Dustmann, 1998; Chiswick, 1999), and displacement problems (Levin et al., 2000). Sociologists have focused on discrimination and glass ceiling issues (Woo, 1994; Waldinger et al., 1998) and career attainment (Tang, 2000). By evaluating what fundamental differences in research activity and performance may exist between native-born and foreign-born academic scientists, this study will clarify what factors commonly affect the differences in outcomes between these two groups.

1.4 Research activity and performance

This study uses three research elements – research collaboration, research grants, and research productivity – as proxies for research activity and performance. First, collaboration is chosen because it is ubiquitous in scientific research (Beaver and Rosen, 1979). The increasingly interdisciplinary, complex, and costly characteristics of modern science encourage more collaborative research activities. Networks for scientific collaboration no longer are confined within a department or institution but increasingly are spread cross-sectionally and internationally (Luukkonen et al., 1993; Adams et al., 2003). Laboratories are being transformed into *collaboratories* in which a combination of technology, tools and infrastructure allows scientists to work with remote facilities and with each other as if they were co-located (Lederberg & Uncapher, 1989; National Research Council, 1993). What makes collaboration crucial is its positive impact on research performance. A recent study (Lee and Bozeman, 2004) found that in the presence of controls for relevant institutional and personal characteristics, the number of collaborators is a robust predictor of publishing productivity. In addition, the measurability of collaboration (often by the number of coauthors or a real number of collaborators) makes it an appropriate proxy for research activity.

Second, grants are *sine qua non* for research. Without grants, research in science would be impossible in most cases. Scientists devote much of their time to securing research grants (Hackett, 1987). Grants help scientists purchase new tools, equipment, and data, hire researchers and student assistants, participate in conferences, support salaries, support students, enhance collaboration, and institutionalize research. The direct and indirect impacts of grants on research performance are used to justify the grants program. Although there are some variations depending on what stage of their careers recipients are in, grants usually play a critical role, particularly in the early careers of scientists (Godin, 2003). As long as resources are a major concern in scientific research, grants should be a focus for observing differences in research activity.

Although collaboration and grants are major indicators of research activities, research productivity is most often used as a measure of research performance. For academic scientists generally involved in teaching, research, and public services, research productivity is frequently measured by the number of publications or patents. As a measure of the output of research, research productivity has a direct and indirect relationship with a variety of factors such as collaboration, grants (Liebert, 1977; Arora and Gambardella, 1996; Gaughan and Bozeman, 2002; Godin, 2003), organization (Long, 1978; Long and McGinnis, 1981), family (Kyvik, 1996; Bellas and Toutkoushian, 1999), age (Meltzer, 1949; Zuckerman, 1972; Lawrence and Blackburn, 1988; Stephan and Levin, 1992), quality of graduate training (Crane, 1965), quality of department (Cole & Cole, 1967; Allison and Long, 1990), gender (Reskin, 1978; Xie and Shauman, 1998; Mahlck, 2001), motivation (Tien and Blackburn, 1996), and time for research (Fox, 1992a). Since this study directly addresses the question, "Are foreign-born scientists more productive?" an examination of research productivity is crucial to it.

1.5 Overview of the chapters

Chapter 2 reviews the literature that is relevant to actual and potential differences between foreign-born and native-born scientists in research activity and performance. The discussion is chiefly of three factors known as the selection effect, the motivation effect, and the embedded disadvantage effect. Based on this discussion, the hypotheses are presented in Chapter 3. The hypotheses include differences between foreign-born scientists and native-born scientists, and differences among foreign-born scientists in research collaboration, grants, and productivity. Chapter 4 builds a framework to analyze the hypotheses, identifying the major determinants of collaboration, grants, and productivity. An analytical framework is created to reveal not only simple descriptive differences but also the independent effect of being foreign-born on research activity and performance and the structural difference of the major determinants between foreign-born and native-born scientists. The relationship of collaboration, grants, and productivity are reciprocal; the three components are the causes and effects for each other. Chapter 5 explains the data, measures, and research method. This study uses curricula vitae and survey data of 443 academic scientists that the Research Value Mapping program collected between 2000 and 2002. ANOVA and a structural equation model (SEM) method are employed to examine the reciprocal relationships among collaboration, grants, and productivity. Chapter 6 presents the findings about the differences between foreign-born and U.S.-born scientists and differences among foreign-born scientists in collaboration, grants, and productivity. First, it provides detailed descriptive analyses for collaboration, research grants, productivity, and the research environment. Second, it presents maximum likelihood results to deal with the impact of collaboration, grants, and productivity, the independent effect of being foreign-born on the three components, and the different effects of independent variables on foreign-born and native-born scientists. Based on these findings, Chapter 7 discusses the implications for the hypotheses and theoretical background. It also discusses the limitations and contributions to the literature of this study, with some suggestions for future research. Finally, Chapter 8 discusses the policy implications from this research.

CHAPTER 2

CHARACTERISTICS AND RESEARCH ENVIRONMENT OF FOREIGN-BORN SCIENTISTS IN THE UNITED STATES

The first section of this chapter reviews theories that might serve to explain differences in performance among scientists. The second section discusses selection, motivation, and embedded disadvantage effects from the standpoint of foreign-born scientists. The selection effect explains that foreign-born scientists may be different – more productive – because of being "selected" in the process of entering to the United States and then surviving as a scientist in an academic position. Similarly, the motivation effect suggests that foreign-born scientists' strong motivation for their research might account for their relatively high productivity. In contrast, however, the embedded disadvantage effect claims that foreign-born scientists are less competent in their research activity and performance because they face inherent difficulties such as different culture, language, lifestyle, and status as foreign-born. The third section reviews the differences among foreign-born scientists primarily based on how closely their language and culture resemble those of the United States. Finally, the fourth section discusses the limitations of the literature and the implications of the literature for this study.

2.1 Inequality of science

Scientists may perform their research differently because of their inherent characteristics. Such inequality of science is often found in the theories of particularism, discrimination, human capital, and structuralism (Tang, 2000). In the first place, particularism is always contrasted with universalism. As Merton (1973) introduced the norm of universalism in science, he argued that "functionally irrelevant" characteristics such as nationality, race, gender, religion, and location should have no bearing on the distribution of rewards. Universalism requires that the assessment of a scientist's work should not be influenced by the personal or social attributes of the scientists and should be subject to "pre-established impersonal criteria (p. 270)." In contrast, particularism involves the consideration of "functionally irrelevant characteristics" in the allocation of resources and rewards. It often plays a big role in rewards and evaluations of science (Chubin and Hackett, 1990; Cole, 1992; Mickelson and Oliver, 1991). Examples of particularism range from cronyism in the review of grant proposals to racism and sexism in the hiring, tenure, and promotion processes and to favoritism or personal opposition in allocating awards, honors, and research fellowships (Tang, 2000). Based on particularistic reasons, Long and Fox (1995) found that women and minorities are less likely to participate in science, have less prestigious positions, have lower productivity, and have less recognition. Foreign-born scientists seem to have particularistic characteristics that go beyond attributes of gender or minority status because they also have different social and cultural characteristics such as language, culture and religion, to name a few.

As a fundamental attribute of particularism, discrimination often causes inequality among scientists. To the degree that race and gender affect the allocation of resources and rewards independently of scientific contributions, discrimination occurs (Long and Fox, 1995). As is well described in "homosocial reproduction" (Kanter, 1993), people are more likely to communicate, hire, or promote members of the same group. Similarly, Cox (1993) identified the "similar-to-me" effect to characterize the desire to associate or work with someone of a similar background. Tang (2000) calls it the "patriot phenomenon," because people are more likely to see things eye to eye with someone of similar demographic or socioeconomic characteristics than with persons of a different race or nationality. But the problem of discrimination is often subtle; it is not discernible but perceived (Choi, 1995).

Human capital theory generally addresses differences in educational attainment among scientists. Different times, institutions, duration, systems, and educational environment cause inequality in science. The notion of human capital is that because foreign-born scientists typically are educated through their undergraduate degree in their home countries, their educational experiences are very different from those of native-born scientists. Although it does not say that the quality of education between foreign countries and the United States always differs, the human capital endowments that inherently are based on a national education environment are often related to the differences in socioeconomic achievements such as workers' productivity (Mincer, 1974; Becker, 1993).

Finally, structuralism indicates that women, minorities, and immigrants tend to concentrate in "peripheral" fields and positions (Tang, 2000). In terms of labor economics, these groups are more likely to work in a low-paying job within small-scale organizations. Shin and colleagues (1988) investigated 1,043 Korean physicians in the United States and found that they are more likely than their native-born counterparts to be in peripheral specialties.[11] Considering the importance of job positions in a research career (Allison and Long, 1990), structuralism might be a cause of inequality among scientists.

Inequality theories make it feasible that scientists' different performances largely depend on their particularistic characteristics, different educational backgrounds, and perceived discrimination. However, these theories do not specifically focus on foreign-born scientists' research activity and performance, rather broadly addressing the potential differences of females and racial minorities. So whether being foreign-born has a positive or negative effect on research activity and performance is not quite clear in these theories, except in the discrimination theory.

2.2 Selection, motivation, and embedded disadvantage effect

Although the inequality theories function as an umbrella for generally described differences among scientists' research activity and performance, selection, motivation, and embedded disadvantage effects are based on the specific features that foreign-born scientists commonly undergo in the process of immigrating to and working in the United States.

2.2.1 Selection effect

Working as a foreign-born scientist in the United States is not a matter of the immigrant's choice. Instead, the decision is the result of government regulations and the intentions of hiring institutions. In this sense, foreign-born scientists, regardless of

[11] Specialties were divided into two categories of core and peripheral depending on income factors.

whether they are an immigrant or a nonimmigrant at the entry level, to a large extent are "selected" by meeting some special need and a certain quality requirement that sometimes exceeds the requirement for their citizen counterparts (Bauer et al., 2000). The selection effect attributes any better performance of foreign-born scientists to the fact that they have been selected.

Selection is found in several practices and occasions, not only in the entry level but also throughout the career path of foreign-born scientists, especially in hiring and promotion practices of academic institutions. Selection effects are often vindicated in the series of comparisons between foreign-born scientists and native-born scientists or among foreign-born scientists, such as a comparison of foreign and native-born students, especially in the entry level of advanced programs; comparison of immigrant scientists in the United States and scientists who are in their home countries; and comparison of scientists staying in the United States and those going back to their home country,

First, when a foreign-born scientist enters the United States for a job, current immigration law (U.S. Immigration and Nationality Act) requires that to gain a work permit for the immigrant an employer must declare that the scientist is especially talented. The immigration law enforces quotas for immigrants obtaining highly skilled jobs. The quota[12] is mainly designated for the H-1B visa that deals with "specialty occupations" requiring the equivalent of a bachelor's degree (U.S. Public Law 106-

[12] The current H-1b quota for 2003 is 195,000. This visa may not be issued to hire non-citizens when there are otherwise qualified and available U.S. workers. Among visas for immigrant scientists, J-1, O-1 and TN-1 are in effect. Many postdoctoral scientists hold a J-1 visa. It allows the holders to teach, study, and research mostly in educational institutions. The 0-1 visa is given to aliens with extraordinary ability in science. The TN-1(Trade NAFTA) category was developed as part of the North American Free Trade Agreement (NAFTA), to facilitate the entry of Canadian and Mexican citizens into the United States to engage in professional business activities on a temporary basis.

313[13]). Although the legal requirement seems loose for screening the quality of doctoral level scientists, the intent to select the "best qualified ones" still provides important guidance to hiring organizations (Salmon, 2004).

Second, it is often reported that foreign students and scientists migrating to the United States generally come from the top of their graduating classes in their countries. A recent Canadian study (Human Resources Development Canada, 1999) shows that Canada's most talented university graduates are migrating to the United States. Its National Graduate Survey indicates that 4,600 Canadians who received postsecondary degrees in 1995 - were living in the United States two years later. This accounts for 1.5% of all Canadian postsecondary graduates. These graduates were high achievers. Indeed, 42% of graduates who moved to the United States for work-related reasons ranked themselves in the top 10% of their class, and 81% in the top quarter. Not only hosting countries (e.g., the United States in this case) but also some sending countries screen the qualifications of those who want to study abroad by setting certain eligibility conditions. In some developing countries, the financial constraints of the nation allow only a restricted number of "selected" students and scholars a chance to study abroad (Leiman, 2004). Such screening processes by sending countries are found even in some developed economies. A German national study, "*German Scientists in the United States* (CRIS International, 2001)," states that "selection of the best" is furthered by the eligibility requirements spelled out by the German scholarship agencies as well as by the selection criteria of the renowned host institutions and research laboratories in the United States, which most young German scholars are heading for. It reports that the results of semi-

[13] American Competitiveness in the Twenty-first Century Act of 2000

structured interviews with 62 current and former German postdoctoral researchers in the United States lend support to the notion of a "crème de la crème" selection in the sense that it is often the very best from among the selected group of German science émigrés who permanently turn their backs on the German academic system. In a recent study, Stephan and Levin (2001) aptly summarize the quality of immigrant scientists,

> "…Foreign-born scientist and engineers who come to the US to receive training, especially at the doctoral or post-doctoral level, are typically among the most able of their contemporaries. Often they passed through two screens: they have been educated at the best institutions in their countries, withstanding intense competition for the limited number of slots available, and they have competed with the best applicants from many countries, including those from the U.S., before being selected for further training in the US (p.65)."

Third, one problem in discussing the quality of immigrant scientists is that they are compared with the rest of people in their country of origin, not directly with U.S. scientists or with scientists elsewhere. The top 10 % from Canada or from China is not equivalent to the top 10 % of the United States. It appears to be very difficult to compare scientists' quality by an international standard. North (1995) partially tackles this problem in two ways – academic preparedness of the foreign-born at entry into the United States and survival of the fittest in the United States. He argues that the academic preparation of the foreign-born admitted to U.S. graduate schools in science and engineering is often said to be equal to or better than that of U.S. applicants (p. 13). Foreign-born students and scientists routinely face sets of gatekeepers – the Educational Testing Service which administers several examinations, Graduate school admissions officials, employer's screenings, and the U.S. immigration system. The GRE math scores of foreign-born students often are much higher than those of the U.S. students (p.41). Although it is unclear whether the GRE score is a good indicator of student quality, at least in the beginning of an academic program, it seems likely that foreign-born students are technically well-prepared or sometimes better prepared than their U.S counterparts.

Fourth, selection also appears among U.S.-trained foreign-born scientists as they choose either to stay in the United States or to return to their home country. While discussing how foreign-born scientists survive in the employment process, North (1995) and Xie and Shauman (2003, p. 196) carefully propose the possibility that less qualified and less successful foreign scientists are more likely to leave the country[14], based on evidence that the researchers collected from interviews. Recently Black and Stephan (2003) found that individuals trained at top programs are more likely to have definite plans to stay in the U.S. than are individuals who are not trained at top programs.[15] In fact, from an employer's point of view, there is no reason to hire less qualified foreigners in a research organization.

Finally, foreign-born scientists undergo a selection process at several points along their career paths. Foreign-born scientists seem to be more closely screened not only in the job application process but also in the tenure process. In this regard, Choi (1995) provides some evidence from her intensive interviews with 46 Asian immigrant scientists. One respondent argued,

---

[14] The return of foreign scientists to their country is explained also by cultural and socioeconomic reasons, not solely by the quality of work (Song, 1991). A more stunning contradiction to the possibility that the returning scientists are those less-qualified is found in Borjas' work (2002). He argues, "…available data contradict the wide-spread perception that the foreign students who remain in the United States are the best and brightest, who find themselves swamped with job offers from American firms once they complete their studies. It turns out that over half of the green cards granted to foreign students are the result of marriage – either to an American citizen or to a permanent resident. And an additional 10 percent of the green cards are granted for other family reasons. In short, almost two-thirds of all permanent residence visas granted to foreign students have nothing to do with "exceptional skills" or "high job demand," but are granted because of family connections" (p. 4).

[15] But there is one exception: Those trained at top medical programs are less likely to stay than are those trained at lower rated medical programs (Black and Stephan, 2003).

> "….the hiring process really demands more outstanding qualifications if you are an Asian. You really cannot be an average. You have to show better qualifications than Americans. So Asians already start out to be really top researchers, they are not an average Ph D."(sic. p. 175)

In her interviews, the phrase "more outstanding qualifications" was commonly echoed by other interviewees. Some respondents also mentioned discrimination that foreign-born scientists often face in various situations, including research evaluation and tenure review (p. 130-137). Given such an environment, surviving discrimination itself seems a different way to show that the foreign-born scientist is highly qualified in her or his specific research (Manrique & Manrique, 1999).

2.2.2 Motivation effect

One of the most frequently cited differences between immigrants and natives is work motivation; immigrants tend to be more motivated to work and achieve success. Economists often argue that immigrants choose to work longer and harder than do natives, largely relying on the opportunity cost theory (Chiswick, 1978; Carliner, 1980; Borjas, 1994). When immigrants move to the United States, they should give up their existing and potential interests in their home countries. To compensate for the opportunity and actual costs, instead, they are highly motivated to succeed in their new jobs in the United States.

Although economists often use data for the general population, the common theme is also echoed in foreign-born scientists. First, their legal status makes foreign scientists more motivated in their research (Espenshade and Rodriguez, 1997). This legal status occurs because the U.S. immigration law prohibits off-campus employment of foreign students (Federal Regulation 8CFR214.2(f)), and foreign scientists who hold J1 or H1 visa must go through a lengthy process to change their jobs. Espenshade and Rodriguez (1997) argued that this legal status partly inspires the motivation that causes foreign-born students to complete their doctorates faster than their native-born counterparts. In contrast to foreign scientists, native-born scientists and students have no restrictions and consequently may be more prone to be distracted by outside employment and broader engagement in social networks and public services.

Second, work motivation seems to be affected by the reasons that foreign scientists in developing countries emigrate to the United States or to some other advanced countries (Song, 1991; Shkolnikov, 1994 and 1995). Song and Shkolnikov pointed out the major common emigration reasons such as better research facilities, access to international scientific community, better informational base, more opportunities for productive research, better treatment of scientists by society, fulfillment of their research, and better living conditions. Based on these reasons, Song and Shkolnikov concluded that emigrant scientists tend to be strongly motivated toward their research.

Finally, a strong wish for survival makes immigrant scientists more motivated for their immediate research work. They are often obsessed by the idea that they must show better performance to survive in their academic position (Choi, 1995; Manrique and Manrique, 1999).

2.2.3 Embedded disadvantage effect

Despite their status as selected and their highly motivated work ethic, foreign-born scientists often suffer from some disadvantages in their research activity and environment. The most notable ones are lack of English proficiency, cultural differences, and perceived discrimination (National Research Council, 1988). These disadvantages are so embedded in their everyday life that foreign-born scientists normally spend a substantial time overcoming these problems. The biggest problem is likely to be language, particularly for newcomers (Cannon, 1988; Garber, 1988; Choi, 1995; North, 1995). Although there are some individual and national differences in the severity of the problem, most newcomers have a language problem. Some immigrants from Europe, India, and Hong Kong tend to have less serious problems because they have been exposed to English through their education and social activities (Espenshade and Fu, 1997). But for the majority of immigrants, language is a daily problem. In Choi's interviews, one full professor who came from Asia confessed that he could express only 65 percent of his ideas (p. 159). It is often reported that communication with students and colleagues is substantially hindered by the lack of English proficiency (Borjas, 2000). DiTomaso (1993) found that foreign-born researchers report fewer communication contacts in the daily research activity than do their native-born counterparts. For these reasons, English language proficiency becomes in many cases a strong predictor for immigrants' occupational success (Tainer, 1988, Kossoudji, 1988; Dustmann, 1994; Chiswick and Miller, 1995; Shields and Price, 1999; Dustmann and van Soest, 2001; Dustmann and Fabbri, 2002). In a study of postdoctoral scientists, COSEUP (2000) found verbal skills are the best indicator of overall career success, and that those with poor English require an average of two more years to find U.S. jobs than those with language proficiency (p. 82).

Having a different cultural background is also a big problem for foreign-born scientists. Like the language problem, lack of understanding the U.S. culture might cause researchers unnecessary costs. For example, the interviews from Choi's study (1995) were recorded like,

> "Asians have some difficulties in socializing themselves at conferences. Compared with Americans, Asians are not likely to participate in social events, like social gatherings. …. Americans tend to belong to social groups, so they make jokes and they know each other. Even though foreigners publish more than Americans, so-called big names in the field do not know those foreigners. So it is difficult to be a great and well-known scholar here (p. 154)."

In a survey of 571 foreign-born biologists in the U.S. university labs, Park (2001) found that language and culture are a big concern for them. Twenty-seven percent reported that language difference influenced their communication with supervisors; 29.2 percent said the differences had some effect on social interactions. From the open-ended questions, she also found that cultural differences in style, expectations, and work attitudes could create misunderstandings that impede the flow of information and the development of science.

Cultural problems are sometimes intermingled with the perception of discrimination. Choi (1995) found that many foreign-born scientists perceive some types of discrimination from grants, tenure promotion, administrative roles, etc. in their workplace. With a nationwide survey of 2,265 foreign-born faculty in U.S. universities, Manrique and Manrique (1999) found that 38 percent[16] of the respondents felt that they had been discriminated against either by fellow faculty or by administrators. Furthermore, nearly half of the respondents knew other foreign-born faculty who had been discriminated against. Although the discrimination is largely based on perception, immigrant scientists are more likely to have some forms of discrimination-related disadvantages that might affect their research activities (Heylin, 1992). Like sports players in away-games, foreign-born scientists may attribute any shortcomings to discrimination. To immigrant faculty, the costs of discrimination and prejudice are obvious; they generate a feeling of isolation and frustration. Manrique and Manrique (1999) found that 66 percent of the respondents agreed that they have to try harder to prove themselves professionally because of their race, 28 percent agreed that their race is a barrier to their professional advancement, and 22 percent agreed that their speech accent is a barrier to their effectiveness as a teacher.

2.3 Differences among foreign-born scientists

Differences may be found not only between foreign-born and native-born scientists but also among the foreign-born scientists themselves. In a study of minority scientists, Joyce Tang (2000) saw a necessity in her analysis to distinguish the native-born from the foreign-born between and within racial groups because there are various differences among foreign-born scientists themselves. Employers may differentiate

[16] Manrique and Manrique measured discriminations by the four question items; “I have been discriminated against by colleagues in my department” (23 percent of respondents agreed), “I have been discriminated against by colleagues outside my department” (26 percent of respondents agreed), “I have been discriminated against by administrators in my institution” (27 percent of respondents agreed), “I know of other foreign-born faculty who have been discriminated against” (47 percent of respondents agreed).

between workers from Europe and workers from Asia, partly because of cultural similarity or lack thereof. To capture diversity in the experiences of scientists and engineers, she emphasizes it is necessary to make inter- and intra-group comparisons by race and birthplace (p. 33).

Based on cultural and language background, one easy distinction could be made between the immigrants from Western countries and from elsewhere, and between immigrant scientists from English-speaking countries and those from non-English-speaking countries. Although the United States is a multicultural society, the cultural foundation is, to a large extent, Judeo-Christian (Hexter, 1995). Such a cultural foundation is likely to give a relative advantage to those who come from Western countries, especially Europe. They could more easily adopt the customs and attitudes of the prevailing U.S. culture. Thiederman (1989) argues that European immigrants have a relatively easy transition because their languages share Romance and Germanic roots with English. However, Asian and Middle Eastern immigrants are faced with greater challenges of pronunciation and emphasis. In this sense, white immigrant scientists, mostly from Europe and Canada, might be more easily assimilated to U.S. culture than nonwhite scientists from abroad (Borjas, 1985).

Similarly, immigrants from English-speaking countries have many more advantages in communication than those from non-English speaking countries. Immigrants from Romance-language countries, for example, may find it easier to learn English than immigrants from Japan or China (Loo, 1985; Niyekawa, 1983). In addition, the amount of exposure to English as a second language may also influence subsequent English-language ability (Espenshade and Fu, 1997). Coming from such countries as

India or Kenya where English is an official, although not dominant, language may strengthen English proficiency. The academic teaching job employment of foreign doctoral recipients in the United States is also comparable to language distance coefficients. Between 1988 and 1996, 8.1 percent of British doctoral recipients took teaching jobs in the United States, while 5.0% of German, 4.6% of Indian, 3.8 % of Italian, 3.5% of French, 3.0 % of Mexican, 2.1 % of Chinese, and 1.4 % of Korean recipients took teaching jobs in the United States (NSF, 1998, p.19).

Foreign-born scientists may be categorized by these two criteria such as culture and language. Foreign-born scientists who come from those countries that satisfy the two criteria have more advantages living as scientists in the United States than do foreign-born scientists from the countries that do not satisfy the conditions. For example, it is very hard to find any disadvantage for a Canadian immigrant in the United States. Likewise, because of the similarity of culture and language, those who come from the United Kingdom, Australia, New Zealand, and most European countries have more advantages than do those who come from other countries, *ceteris paribus*. Among the non-European countries, Indian immigrants generally have a relative advantage because of their greater level of English proficiency. In a similar way, Chiswick and Miller (1998) developed a composite index of linguistic distance, a measure of the difficulty of learning a foreign language for English-speaking Americans. According to the distance index, European languages (e.g., German, French, Italian, Spanish, Swedish, Rumanian, and Norwegian) are not nearly so far away as non-European languages (e.g., Bengali, Korean, Japanese, Cantonese, Mandarin, Arabic, Hindi, and Turkish). In a classic study of cultural distance among nations, Hofstede (1980) quantified the distance by using four major factors such as power distance (the degree of equality, or inequality, between people in the country's society), uncertainty avoidance (the level of tolerance for uncertainty and ambiguity within the society — i.e. unstructured situations) individualism (the degree the society reinforces individual or collective achievement and interpersonal relationships), and masculinity (the degree the society reinforces, or does not reinforce, the traditional masculine work role model of male achievement, control, and power). According to his composite index [see Table 5 and note in Appendix A], countries such as China, Egypt, Iran, Korea, Japan, and Turkey are farthest away from the United States, whereas Canada, the United Kingdom, and New Zealand are closest to the United States.

While the cultural and language criteria deal with the embedded problem, however, the assimilation effect focuses on the time-dependent difference (Carliner, 2000). It simply indicates that the differences between the foreign-born and native-born scientists disappear with an increase in the years that the foreign-born live in the United States. Because immigrants grow accustomed to American culture and language as time passes, the embedded disadvantages are not significantly noticeable between native-born scientists and foreign-born scientists who have stayed in the United States for a long time.

2.4 Summary and implications of the literature

Whether one group of scientists is or is not different from another group of scientists in research activity and performance seems to require an examination of various factors. A group could be based on race, nationality, religion, minority, gender, and so forth. Previous studies broadly assume that scientists who are from the same background may differ from those who are not, largely depending on particularism, human capital, (perceived) discrimination, and structuralism. Particularism evinces that "functionally irrelevant characteristics" such as race and gender often play an important role in research activity. The human capital theory holds that differences in educational attainment and background among scientists, particularly based on nationality, create differences in research activity and performance among scientists. Discrimination theory also says that scientists who belong to a racial minority or who are members of a minority and also females often face discrimination in their work environment or perceive that there is such discrimination. This in turn makes them less competitive in their research activity. Structuralism suggests that women, minority, and immigrants might be different in their research activity because they tend to concentrate in "peripheral" fields and positions.

Although the four theories provide important reasons for the actual and potential differences among scientists, they are not specifically focused on the issues of foreign-born scientists, but more likely on the issues of gender and minority status. From the literature, this study reviewed specific reasons why foreign-born scientists could be different and then organized them into three themes of selection effect, motivation effect, and embedded disadvantage effect. First, the selection effect indicates that foreign-born scientists might be more productive in their research since they are "selected" for their entry into the United States and throughout their career path. The U.S. legal guidelines, the competition among foreign scientists for limited slots in U.S. institutions, and the perceived higher expectancy for immigrant scientists in the tenure process contribute to the series of selections. Second, the literature often indicates that immigrant scientists are more motivated in their research because most of them came to do research, at least in the initial stage, and want to stay in the United States by showing outstanding performance. Finally, in contrast to the positive selection and motivation effects, foreign-born scientists might be less competitive than native-born scientists in their research activity and performance because of language difficulties, cultural differences and perceived discrimination.

These ideas seem to provide an important basis for understanding actual and potential differences of foreign-born scientists in their research activity and performance. However, the literature has some limitations in framing and theorizing about these effects because the causal connection between input factors such as selection, motivation, and embedded disadvantages and the outcome factors such as foreign-born scientists' collaboration, grants, and productivity have rarely been studied, primarily because of the difficulty in collecting empirical data. Data are not readily available to identify how foreign-born scientists differ in academic qualification at the entry level. Similar problems are involved in identifying who stays and who leaves and the differences between them, what role being "foreign-born" plays at various career stages, how different motivational factors contribute to foreign-born scientists' research performance, and how and what discrimination affects foreign-born scientists' research activity. In most cases, the evidence that previous studies are based upon is anecdotal. In particular, discrimination is too subtle to be easily documented. Stereotypical perceptions often prevail without solid evidences. Taken as a whole, the most serious missing link in the literature is the lack of identification of real differences as a result of being foreign-born. However, if this is its weakness, its strength is its success in creating an assumption that foreign-born scientists might be different. The effects should be identified from the unique situation and environment that foreign-born scientists undergo.

CHAPTER 3

HYPOTHESES

This chapter discusses the hypotheses of this study. The selection, motivation, and embedded disadvantage effects provide important bases for the hypotheses. Each section deals with research collaboration (Section 3.1), research grants (Section 3.2), and research productivity (Section 3.3).

3.1 Research collaboration

Collaboration is, by definition, a social activity; it largely relies on personal communication and networks. In social gatherings, language and culture are important components. Without fluency in English and an understanding of U.S. culture, collaboration may be hindered. DiTomaso and colleagues (1993) found that foreign-born scientists have fewer communication contacts. Similarly, Kusa (1988) argued that communication skills and cultural acclimation are the areas where immigrants are likely to be weakest.

In addition to the language and cultural barriers, lack of experiences, information, and the presence of discrimination also might hinder the collaboration of foreign-born scientists. However, because of this very problem of language and culture, they may strengthen their collaboration with those who have the same language and cultural background (Qin, 1995). As indicated in the "similar-to-me" effect, foreign-born scientists also might have some types of embedded disadvantages in their collaboration activity. For similar reasons, foreign-born scientists who came from countries with language and cultural similarities to the United States might engage in more collaboration than those who came from less advantageous countries.

> H1: Foreign-born scientists engage in fewer collaborations than do native-born scientists.
>
> H2: Foreign-born scientists who came from countries where English is a major spoken language and Western culture is dominant engage in more collaboration than other foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant.

3.2 Research grants

Several factors may come into play to create differences between foreign-born scientists and native-born scientists in securing research grants. First, because winning grants often relies on personal ties and socializing with members of the research community and funding organizations, foreign-born scientists might be disadvantaged in many ways. As Liebert (1976) argues, grants are distributed not only by performance criteria but also by particularism, or favor. Although a strong belief in "meritocratic universalism" (Cole and Cole, 1973) exists in fund-granting decisions, "some special connection" with the grantor organization and its personnel is beneficial (Liebert, 1976; Liebert, 1977). Many research projects involve various funding sources such as industry, government agencies, and nonprofit organizations. Active entrepreneurship often is needed in "attracting" money from them. To compete in such an environment, foreign-born scientists need to be comparable to their native-born counterparts in communication skills and ability to network with potential supporters. This is not always something foreign-born scientists do well.

Second, because of their limited networks, foreign-born scientists often are unable to reach all the sources of grants. They may rely more on “universal” competition grants that anyone can apply for based on his or her research merit rather than entrepreneurially developing funding sources. Some research grants restrict the eligibility of the applicant by citizenship, particularly in defense- and security-related research (Norris, 2004). As shown in a case of techno-nationalism (Ostry and Nelson, 1995), the legal status of foreign-born scientists and national security restrictions may give a relative advantage to native-born scientists. Such conditions may hinder newly arrived young foreign-born scientists who are more likely to be classified as temporary residents. Although there is no formal requirement for citizenship or an evidence of a “good” resident in most cases, foreign-born scientists intentionally or unintentionally are likely to avoid becoming involved in grant-getting activity in this kind of nationality-sensitive research.

Considering the importance of language and cultural proximity in winning grants, there also might be differences between those who came from more advantageous countries in terms of language and culture and those who came from less advantageous countries.

> H3. Foreign-born scientists have fewer research grants and a lower acceptance rate of proposals than do native-born scientists.
>
> H4. Foreign-born scientists who came from the countries where English is a major spoken language and Western culture is dominant tend to have more grants and a higher acceptance rate of proposals than foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant.

3.3 Research productivity

In contrast to their difficulties in research collaboration and in securing grants, foreign-born scientists may be more productive than their native-born counterparts because of the effects of selection and motivation. Foreign-born scientists are “selected” at several points in their career paths and tend to be more motivated for their research. Because of either their interest in research (Choi, 1995; Waldinger et al., 1998) or because of discrimination in their work environment (Woo, 1994), they also tend to stay longer in research positions instead of moving to administrative or managerial positions. In a study of career changes, Tang (2000) also found that Asians were far more likely to remain in engineering or engineering-related positions than their white counterparts, with zero-order effects for the foreign-born essentially unchanged after statistical controls. Such greater career stability and research orientation may contribute to higher research productivity among foreign-born scientists.

In the meantime, as long as similarly selected and motivated, foreign-born scientists who came from more advantageous countries in terms of language and culture might have higher productivity, compared with foreign-born scientists from less advantageous countries, since the former might have less difficulties in research activity.

H5. Foreign-born scientists are more productive than native-born scientists.

H6. Foreign-born scientists who came from the countries where English is a major spoken language and Western culture is dominant are more productive than other foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant.

CHAPTER 4

ANALYTICAL AND CONCEPTUAL FRAMEWORK

The main purpose of this chapter is to propose a framework to analyze the hypothesized differences between foreign-born and native-born scientists in research collaboration, grants, and productivity. The analysis of differences is not so straightforward because it should deal with the complex interrelationship of collaboration, grants, and productivity. Section 4.1 describes the stages and processes of analyses. Section 4.2 frames the model of collaboration, grants, and productivity by which the analysis examines how "being foreign-born" makes differences and what factors are more important for foreign-born scientists than for their native-born counterparts. Finally, Section 4.3 summarizes the discussion and briefly evaluates the model.

4.1 Stages of analysis

The first major task (Stage 1) in this study is to see if foreign-born scientists have different levels of collaboration, grants, and productivity from their native-born counterparts. Multiple indicators are developed (see Section 5.5) and compared between foreign-born and native-born scientists and among foreign-born scientists.

The second task (Stage 2) examines whether being a foreign-born scientist has any impact on collaboration, grants, and productivity. Essential questions include: Is any difference in collaboration, grants, or productivity caused by the status of being foreign-born? In other words, how significant is being a foreign-born scientist to determining research activity and performance? These questions inherently require, while controlling for relevant variables, an independent effect on research from being a foreign-born scientist. Therefore, it should identify important variables that may significantly determine collaboration, grants, and productivity from various factors such as demographic, organizational, and environmental factors.

The last task (Stage 3) identifies which factors account for the differences between foreign-born and native-born scientists in collaboration, grants, and productivity. Although the research does not hypothesize specific reasons or factors that may have causal impacts between foreign-born and native-born scientists, this stage of analysis enriches the reasons why they are (or are not) different.

Table 3. Three stages of analysis

Stage	Framework	Analysis	Outcomes of Interest
1	Foreign-born (FBs) vs. Native-born (NBs)	Simple Comparison	"Foreign-born scientists are (not) different"
2	Foreign-born, and collaboration, grants, and productivity variables in the same model	Independent effect of "FBs", controlling for others	"Being FBs makes (no) differences in research"
3	Collaboration, grants, and productivity variables in two different models (FBs and NBs)	Comparison of determinant structures in the two different models	"Some variables determines FBs' collaboration, grants, and productivity, differently from NBs"

4.2 Models of collaboration, grants, and productivity

Beyond the simple comparison of several indicators, stages 2 and 3 of the analysis address the independent effect of being foreign-born and the structural differences of foreign-born scientists' research activity and performance. Section 4.2.1 deals with the reciprocal relationship among collaboration, grants, and productivity. Section 4.2.2 identifies important explanatory variables that are assumed to affect collaboration, grants, and productivity. The goal of framing the models is to see if being foreign-born has independent power to explain, when individual, institutional and environmental factors are controlled for, and how each variable works differently research collaboration, grants, and productivity of foreign-born scientists from that of native-born scientists.

4.2.1 Reciprocal relationship of collaboration, grants, and productivity

One of the important methodological challenges of this study is to tackle the reciprocal relationship among collaboration, grants, and productivity. The literature often reports a significant correlation among the three components. But it is rare to formulate a reciprocal relationship in a single study. The reciprocal relationship is supported by the bidirectional relationship.

Collaboration → Productivity

Collaboration is strongly related to productivity. Since Lotka's pioneering works (1926) on the productivity of scientists, many studies have confirmed a strong relationship between collaboration and scientific productivity. Analyzing 592 scientists' publications and collaborative activities, Price and Beaver (1966) found that "there is a good correlation between the productivities and the amount of collaboration of the authors. The most prolific [person] is also by far the most engaged in collaboration, and three of the four next most prolific are also among the next most frequently collaborating." With interviews of 41 Nobel laureates in science, Zuckerman (1967) identified a strong relationship between collaboration and productivity; laureates published more and were more apt to collaborate than a matched sample of scientists. In a collaboration study of musicology, Pao (1982) also identified a strong relationship between collaboration and productivity. Although only 15% of the literature of musicology was the result of collaborative authorship, the musicologists collaborating most were also the most productive. Applying a normalized diversity measure to study the productivity of authors, Pao found a high degree of correlation between productivity and collaboration in computational musicology.

Pravdic and Oliuic-Vukovic (1986) analyzed collaborative patterns in chemistry at both the individual and group levels. They found that scientific output as measured by publications is closely dependent on the frequency of collaboration among authors. Particular effects on productivity depend upon the type of links; while collaboration with high-productivity scientists tends to increase personal productivity, collaboration with low-productivity scientists generally decreases it. Furthermore, the most prolific authors seem to collaborate most frequently, and authors at all levels of productivity tend to collaborate more with highly productive authors than with less productive authors.

Given the strong relationship between collaboration and productivity, what elements in collaboration affect productivity? Despite the lack of direct causal explanations, several elements have been identified, including division of labor, complementary skills, time efficiency, intellectual stimulus, intellectual renewal or new skills learned from collaborator, companionship and a sounding board for discussion[17] of research, access to equipment, communication of new information and new publishing opportunities. As is often the case in business and management, the additional input of labor is expected to raise its marginal productivity. Although the logic cannot directly be utilized in scientific research activity, the elements necessary to induce collaboration seem also to serve to increase productivity, regardless of the scientists' initial intention.

Recently Melin (2000) surveyed 195 university professors about the major reasons for collaboration and the chief benefits of collaboration. In open-ended questions, the respondents' most often reported (41%) motive for collaboration is that the "coauthor has special competence." Other common motives included "coauthor has special data or equipment (20%)," "social reasons: old friends, past collaboration (16%)," "supervisor-student relation (14%)," and "development and testing of new methods (9%)." With respect to the benefits of collaboration, the respondents pointed to "increased knowledge (38%)," "higher scientific quality (30%)," "contact and connections for future work (25%)," and "generation of new ideas (17%)." Based on the data, Melin concluded that scientists collaborate for strong pragmatic reasons that are largely consistent with productivity-oriented collaboration.

Collaboration enhances productivity in total and per-capita article production (Durden and Perri, 1995). The editorial decisions of journals corroborate that collaboration has a direct effect on productivity. Several studies found that collaborated

[17] Pelz and Andrews (1966) summarized well how communication in collaboration has a significant effect on research performance: "productivity is associated with scientists' communication among colleagues. Their measures of communication included contacts via memos and meetings, as well as conversation, and the relationship between communication and productivity held even after controlling for experience and supervisory status. Communication enhances productivity, they say, because it provides ideas, helps catch errors, and promotes competition and reward."

papers are more likely to be accepted in journals than are papers with single authors or few collaborators (Zuckerman and Merton, 1971; Presser, 1980; Gordon, 1980; Lawani, 1986; Bayer and Smart, 1991; Hollis, 2001).

Not only collaboration with faculty colleagues but also collaboration with graduate students is reported to have a positive relationship with faculty research productivity (Gorman and Scruggs, 1984). Dundar and Lewis (1998) found that the percentage of graduate students who were hired as research assistants is positively correlated with the faculty publication productivity. Although there is a tendency for faculty members to not seriously consider their [graduate] students as collaborators, student involvement in research sometimes makes a significant contribution to the project. Conversely, faculty members benefit from the involvement in the student's dissertation research. Kelly and Warmbrod (1986) argued that the number of doctoral committees chaired successfully resulted in higher faculty research productivity.

Collaboration → Grants

Collaboration also has an impact on grants because a progressively larger collaboration pool increases the probability of receiving grants because of the funding agency's policy toward collaboration (Ham and Mowery, 1998) and group capability (Stankiewicz, 1979), particularly for interdisciplinary research collaboration (Landry and Amara, 1998). Many granting agencies and universities have preferentially funded collaborative research in the belief that it may lead to new insights (Landry and Amara, 1998). Chen (1997) found that collaborated projects have a higher acceptance rate in research funding decision-making.[18] It is often the case in small collaborations as well as large ones that several scientists work together to seek grants by collaborating as "CO-PIs."

Grants → Collaboration

Grants have a strong impact on collaboration. Depending on the amount and duration of grants, the scientists may hire more assistant scientists – e.g., postdocs and graduate student assistants – and expand their collaborative work with more scientists within and outside their organization. With continuous support of grants, research is often institutionalized and conducted in a team-based work environment (Knorr-Cetina, 1999). By examining 2.4 million scientific papers written in 110 leading U.S. universities from 1981 to 1999, Adams and colleagues found that team size increases with funding, suggesting that funding drives large projects that are intensive in the use of equipment and research assistants (Adams et al., 2002). A recent survey of NSF's Efficiency of Grant Size and Duration (Ballou et al., 2002)[19] shows a positive impact of research funds on collaboration and productivity. With increased funds and duration, researchers responded that they would "pursue innovative ideas (96%)," "collaborate with researchers in the area of research (92%)," "achieve the research objective within the specified time (92%)," "collaborate with research in different areas of research (84%), " and "obtain quality personnel (85%)." Findings from several studies similarly indicate that the greater the research funding and the number of publications, the more

[18] In a similar vein, some studies show that coauthored papers are more likely to be cited (Fox, 1992b).
[19] With decreased research funds, the respondents pointed out most frequently that it would have negative impact on the ability to "achieve the research objectives within the specified time (67%)," "obtain quality personnel (55%)," and "collaborate with researchers in the area of research (50%)."

intense the collaboration (Liebert, 1977; Geisler and Rubenstein, 1989; Peters and Fusfeld, 1983; Onida and Malerba, 1989; Rebne, 1989; Mitchell and Rebne, 1995; and Landry et al., 1996). Beyond the simple co-relationship among grant, collaboration, and productivity, Landry and Amara (1998) found that many granting agencies and universities have preferentially funded collaborative research in the belief that it may lead to new insights.

Grant → Productivity

Both collaboration and productivity may be wrapped up in grants and contracts success. In the first place, most grants are for teams of researchers, and those who are working on grants often have commitments to devote a certain percentage of their time to collaborative or team-based goals, projects and publications. Second, if one is the principal investigator (PI) in the grant, it is often the case that one has an extended set of collaborations not only because of formal contractual commitments but also because of norms of crediting the PI in publication when the PI's data or experimental apparatus are used. In generals, those with grants and larger grants (in funding dollar terms) are expected in this study to collaborate more and to have more publications. The dollar amount of the grant is not expected to be nearly as important as simply having been awarded grants or contracts. In the first place, dollar amounts are often related to field- and discipline-specific dynamics, such as the expense of equipment, and, in the second place, earlier research has shown that research productivity is not monotonic in its relationship to magnitude of funding (Kingsley, Bozeman, and Coker, 1996). Getting a grant of whatever size may not only facilitate publication productivity in the professions, but may also depend on it (Heffner, 1981). Grantors often turn to the professions for assessments of the competence of a grantee to do work of some authority or distinction (Jencks and Riesman, 1969).

Productivity → Collaboration

Increases in the intensity of collaboration are associated with increases in the number of publications and citations (Luukkonen et al., 1992). Such productivity may affect the level of collaboration and grants in many ways. First, people who are more productive generally have more resources (especially funding) and others wish to take advantage of those resources, seeking out collaboration opportunities. Cumulative advantage theory (Merton, 1968) supports a feedback process in which earlier productivity contributes to differential resources and recognition. Second, people who are more productive have more S&T human capital, again leading others to seek them out for collaboration. Third, people who are more productive have less pressure on them to have single-authored papers and can choose to collaborate even in cases when there is not "efficiency" in terms of improving their near-term output. Fourth, productive scientists are more likely to be known to more people in their discipline. Such a "familiarity" factor raises the possibility of collaborating with others. Similarly, productive scientists are more likely to be included in intra- and inter-organizational networks. Such extensive exposure of productive scientists to networks enhances their opportunities to collaborate with others.

<u>Productivity → Grants</u>

In one of the classic studies in the relationship between grants and research performance, Liebert (1977) identified that career articles, recent publications, and field resources are major determinants of getting grants. With the sample of 5,378 college faculty, he found a major dependence in getting grants on publication productivity, but a very minor (generally insignificant) influence by institutional and personal status such as quality of institution (percentage of doctorate, revenue per student, research revenue), professional status (paid consultant), personal characteristics, and geographical location. It is likely that the more productive one is, the better the odds of winning grants, because a higher number of career articles and recent publications often assure the quality of the scientist (Liebert, 1977). Similarly, Benowitz (1997) observed that awards are often given for past accomplishments, including ground-breaking research, a solid publication, and notable professional activities.

4.2.2 Determinants of collaboration, grants, and productivity

What variables should be included as determinants for collaboration, grants, and productivity depends on research interest and importance. Since this study focuses on differences between foreign-born and native-born scientists, the included variables are relevant to the ways in which foreign-born scientists may engage differently in research. In addition to relevancy, the important variables from the literature are also included as determinants.

Age (career)

Age correlates such as career age and rank (tenure) appear to have positive relationships with collaboration, grants, and productivity, mainly because of cumulative advantages. Compared with young faculty members, senior faculty members have more experience and are involved in a broader professional network. Senior scientists usually have their own established research team or group in which immediate collaboration already exists. They also are more likely to have doctoral students and postdocs than are junior faculty, particularly assistant professors. In addition, senior scientists have a larger coauthorship pool upon which coauthorship publications heavily depend. Although there is a substantial difference between junior and senior scientists in the level of collaboration, collaboration does not always increase with age and rank.

Similarly, established senior scientists generally have more advantages in securing grants. Through their grant-getting experiences, network, visibility, and "”evaluated and known” quality from previous research, seasoned scientists may have an accumulative advantage in securing grants (Liebert, 1976). Agencies have also recognized that it is difficult for young career scientists to compete with veterans who know what reviewers want (Benowitz, 1997). From the grantor’s point of view, it seems that young scientists often do not assure the grantor of their quality of work. For these reasons, solicited grants are more available to more established scientists than less established ones.

In the meantime, the age effect on productivity is generally along the life cycle effect. Lehman (1953) argued that scientists’ major contributions are most likely to occur in their late 30s or early 40s, and thereafter decline in frequency. He emphasized that the age peak occurred earlier in abstract and theoretical disciplines such as theoretical physics and later in more empirically based fields such as biology. Pelz and Andrews (1966) found two productivity peaks; the first one in scientists' late 30s and early 40s and a second one at age 50. Stephen Cole (1976), on the other hand, reported a slightly curvilinear relationship between age and quality of publications for a cross-section of academics in six scientific fields. In a more recent study of age and productivity, Levin and Stephan (1991) found that life cycle effects are present in a fully specified model of publishing productivity that, among other things, controls for individual fixed effects such as motivation and ability. Using the data of 903 natural scientists, they found evidence that, on average, scientists become less productive as they age and that the age effect is attributed to age per se and not to the possibility that older scientists in the sample have different attributes, values, or access to resources than younger members of the sample.

Regarding the assimilation effect on foreign-born scientists, age has an important meaning in this study. Age (career age) often indicates a scientist's length of stay in the United States, because most of the foreign-born scientists in the United States attended graduate school in the United States.

Gender

Gender often determines the level of research activity and performance. Male scientists are engaged in more collaboration than female scientists. Cole (1981) observed that women are often excluded from important networks with the result that their opportunities for collaboration in research are more restricted. Since female scientists tend to have more responsibilities in child-raising and family relations, their collaboration is likely to be more limited than male scientists. Another reason is that the United States still has fewer female than male scientists. It is much more difficult for female scientists to collaborate with female scientists than for male scientists to collaborate with male scientists. In the professional network[20], male scientists are more involved than are their female counterparts (Cameron and Blackburn, 1981). Kyvik and Teigen (1996) found that more men than women are engaged in more collaboration, and that women are more interested in internal collaboration than in external collaboration beyond their immediate organization. They also argued that collaboration is more effective on productivity in women than in men. Similar reasons such as female scientists' family obligations and disadvantages in networking may also account for the difference in research grants

Women tend to have somewhat lower publication rates than men. The lesser productivity of females has been established in dozens of studies covering diverse fields, spanning decades, and using myriad measures (Astin, 1969; Hamovitch and Morgenstern, 1977; Fox, 1983; Cole and Zuckerman, 1984; Long, 1987; Creamer, 1998; Bellas and Toutkoushian, 1999). As Long (1992) pointed out, the loss of time available for scientific work as a result of family obligations is likely to be greater for women, because women are more likely to be the primary caretakers in families. Being married and having children is negatively related to productivity for women (Astin, 1969). Also,

---

[20] According to Cameron and Blackburn (1981), professional network involvement was measured by response to eight questions asking for the scientists having a colleague in a variety of professional settings (e.g., member of journal editorial board, officer in professional association). The results scale was divided at the median to create a high and low network involvement measure.

sex discrimination may make it more difficult for females to obtain resources and this may, in turn, limit their ability to publish.

However, not all researchers agree that female scientists are always less productive. According to Clemente (1973), Wanner and colleagues (1981), and Long (1992), female scientists are not less productive than male scientists. Wanner and colleagues used a sample of 17,399 university faculty from all fields. Particularly, Long (1992) found that male scientists than female scientists are more productive in the first decade of the career but are less productive later in the career since female scientists are over-represented among non-publishers and underrepresented among the extremely productive. Xie and Shauman (1998) and Sax and colleagues (2002) again confirmed a decline in the effects of gender on scientific productivity, attributing this in part to the increasing ratio of females in scientific jobs.

Departmental quality

The quality of an academic department seems to affect collaboration, grants, and productivity. Prestigious departments generally have more research resources and more "star" scientists in more specific research areas. Such advantages help their scientists to collaborate easily with experts inside the organization and also to attract more joint research and R&D from outsiders, including other universities, government agencies, and industry.

Institutional differences have a significant impact on grants. For example, the academic R&D of the top 30 institutions accounts for 40 percent of the U.S. total academic R&D in 2001(*NSF Indicator 2004*, A5-5). Not only federal grants but also industry grants disproportionately provide more for the top-tier schools. The scientists in the top institutions also may benefit from institutional cumulative advantage[21] (Dey et al., 1997) and a halo effect (Astin and Solmon, 1981; Grunig, 1997) in obtaining grants.

Departmental quality also has a positive impact on research productivity. Although it is unclear whether good departments hire the best scientists or good departments encourage and facilitate research productivity (Allison and Long, 1990), it is often reported that prestigious departments have a higher per capita research output for three notable reasons. These three are better facilities (Hagstrom, 1965), more intellectual stimulation (Pelz and Andrews, 1966), and higher motivation (Zuckerman, 1967; Reskin, 1977). Allison and Long (1990) found that the effect of departmental affiliation on productivity is more important than the effect of productivity on departmental affiliation.

Research preference

It is unrealistic to assume that all scientists have the same motivation for research. Some scientists stick closely to research per se throughout their career, whereas other scientists devote their time to administration, public service, or entrepreneurial activity. Therefore, orientation towards research might make a difference in research activity and performance. Expectancy theory provides a rationale for how individual needs, values, and perceptions about the environment determine one's behavior (Galbraith and Cummings, 1967; Vroom, 1964). More research-motivated researchers might maintain

[21] In this regard, Rose (1986, p96) succinctly summarized the advantages: "The newest and most modern facility attracts eminent scientists to an institution; the scientists win vast numbers of research grants; and the resulting prestige makes the host institutions a prime candidate for any additional facility support that becomes available. The elite research universities are quite naturally pleased with this process."

or expand their research activity and performance more than their less research-motivated counterparts. In a study of intrinsic and extrinsic motivation in scientists, Tien and Blackburn (1996) argue that research interest (intrinsic) plays a more important role than extrinsic motivation in scientists' research activity and performance (also, Finkelstein, 1984; Blackburn et al., 1978; Fulton and Trow, 1974; Blackburn et al., 1991). How inner motivation makes a difference in scientific performance has long been explained by the so-called "sacred spark," which maintains that scientists engage in research because they have a strong inner compulsion or motivation. According to Jonathan and Stephan Cole (1973, p.62): "Some scientists, no doubt, would continue to work hard on their research even if the norms prescribed that the researcher must remain anonymous. These scientists have the *sacred spark*. They are motivated by an inner drive to do science and by a sheer love of the work." Eminent scientists are highly motivated, intellectually self-reliant, and confident in their ideas (Merton, 1973; Pelz and Andrews, 1966). Highly research-motivated scientists focus more on continuous research rather than other activities, are intensely interested in the detailed workings of nature, and are committed to the elaboration of theories (Hagstrom, 1965).

Perceived discrimination

Mertonian norms of science (universalism, communism, disinterestedness, and organized skepticism) do not address discrimination issues in science. Science is often assumed to be an entity in which "pre-established impersonal criteria" dominate. However, from time to time, discrimination appears to be a significant factor in scientists' collaboration and grant activity. Scientists who are in a minority status and are of a different nationality often claim that they are discriminated, against not physically, but in *perceived ways* (Choi, 1995). Once the scientists feel that the research environment discriminates against them, they are likely to be less active in seeking collaborators, at least local ones, and this may well have negative effects on grants and productivity. It is anticipated those who perceive discrimination will be less productive and have fewer grants and fewer collaborators.

Geographical proximity (Cosmopolitan scale)

Geographical proximity is important in determining collaboration (Landry et al., 1996; Landry and Amara, 1998). Within particular families of scientific disciplines, collaboration increases with geographical proximity (Landry et al., 1996). To avoid potential transaction costs, people collaborate more with people in their immediate organization than with people at a longer distance (Kraut et al., 1987). In the cases of Canada, Australia, and the United Kingdom, Katz (1994) found that research collaboration decreases exponentially with the distance separating the collaborative partners.

Geographical proximity is often mixed with the concept of boundary or group-orientation. Merton (1949) divided the researchers in an industrial research lab into the "cosmopolitans" and the "locals." The former are oriented toward success as members of their profession and more productive, but their interest in the company is limited to its adequacy as a provider of facilities for them to pursue their professional work. However, the locals are good company men, but their interest is likely to be less in their work than in their advancement in the company. Pelz and colleagues (1953) used the terms "institution-oriented" and "science-oriented" to make a very similar distinction. The science-oriented scientists are more cosmopolitan, whereas the institution-oriented scientists are more local. The concept of cosmopolitan and local from Merton and Pelz and colleagues seems have advantages in distinguishing scientists based on their behavior and work orientation, but it does not address a geographical (albeit not a pure physical distance) and institutional distance.

Job Mobility

Scientists' job mobility might have some impact on collaboration. Through changing jobs from institution to institution, scientists could have chance to collaborate with whoever they came in contact with in different organizations (Wegener, 1991). The social ties formed in prior organizations help scientists expand their external collaboration beyond their immediate institutions (Hicks and Katz, 1996). However, mobility also might have a negative effect on collaboration, primarily because a newcomer needs time to develop a collaborative network in the new organization. As for foreign-born scientists, it is interesting to examine if any difference in mobility causes differences in collaboration between foreign-born and native-born scientists.

Affiliation with research centers

Affiliation with certain research programs or centers may have a different effect on the probability of scientists' securing grants. The government often supports ear-marked money for certain strategic research areas and centers (NRC, 1987). Likewise, industry also supports R&D for academic research through university research centers or groups. ERCs (Engineering Research Centers) are a typical example. The program started in the early 1980s because of strong appeals to enhance technological competitiveness. NSF provided a total of $51.7 million for 21 centers during the fiscal years of 1994-1995. Along with the NSF's direct grants, member firms and university/state governments, respectively, supported $53.7 million and $73.5 million (Parker, 1997). Although it is not clear how much R&D was distributed per capita, the scientists who are affiliated with these centers might have more opportunities to obtain research grants.

Job satisfaction

Job satisfaction has a significant impact on scientists' research productivity Pfeffer and Langton (1993) and Babu and Singh (1998). Job satisfaction as a construct usually includes several things such as satisfaction with pay (Pfeffer and Langton, 1993), satisfaction with research (Bess, 1981; Finkelstein, 1984; Babu and Singh, 1998), satisfaction with the research environment (Finkelstein, 1984; Pfeffer and Langton, 1993), respect, esteem, and recognition from the department and others (Bess, 1981; Finkelstein, 1984; Kelly and Warmbrod, 1986), and satisfaction with personal life (Bess, 1981; Finkelstein, 1984). Although it is not clear whether a scientist's satisfaction increases his or her research performance or vice versa, it is important to include job satisfaction in the study of productivity because to some extent it may control for the scientist's personal engagement in research. Job satisfaction is especially important in assessing research performance by foreign-born scientists because they are assumed to be less satisfied with their jobs.

Family relations (spouse's job)

Researchers whose spouses are full-time homemakers could have more time to spend on research than those who have spouses who are not full-time homemakers (Bellas (1992). In particular, married men who have unemployed wives who assume primary responsibility for housework and child care can devote time and energy to careers and jobs (Papanek, 1973; Coverman, 1989). In this sense, female scientists generally are disadvantaged because their spouses are more likely not to be full-time homemakers.

Nonacademic job experiences

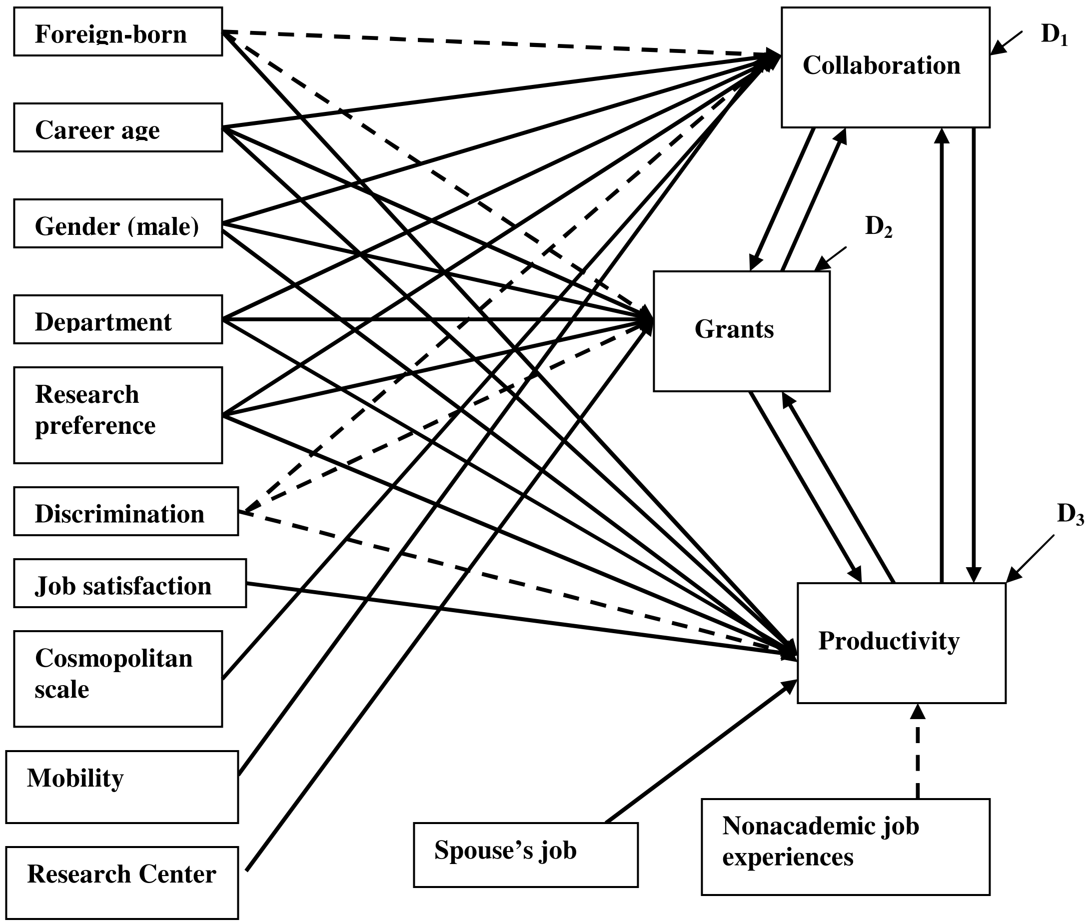
Nonacademic job experiences often have a negative effect on scientists' publication productivity (Lin & Bozeman, 2004; Dietz, 2004). Relying on what he called the "homogeny effect," Dietz (2004) found that scientists who exhibit a career pattern of relatively uninterrupted job sequences in academia have higher publication productivity than those who do not. By using 956 curricula vitae from the RVM data set, he found that productivity has a negative relationship with the proportion of career years worked in industry jobs and also a negative relationship with starting one's career in industry or government.

Field

Depending on the specific discipline, various differences exist in collaboration, grants, and publication. Experimental scientists tend to collaborate more than theoretical scientists (Meadows and O'Connor, 1971; Gordon, 1980). In experimental research, scientists often use large and costly instrumentation that requires a large number of collaborators with some division of labor. Applied scientists are more engaged in collaboration (Katz and Martin, 1997), since applied research is more interdisciplinary and requires a wider range of skills (Hagstrom, 1965).

Grant availability varies among disciplines because some disciplines have more grant opportunities than others. In terms of technology innovation initiatives (e.g., National Nanotechnology Initiative), research grants are often earmarked for a specific area of research. Some fields attract more grants, including industry and nonprofit organizations, than others do because there is greater social value attached to their products, whatever those products may be or however many of them are produced (Liebert, 1977).

Publishing patterns and productivity varies among disciplines (Bonzi, 1992). Scientists in some disciplines have more publications than scientists in other disciplines. For example, researchers in "hard" sciences generally have more publications than those in "soft" sciences (Biglan, 1973; Wanner et al., 1982). Even among natural scientists, experimental scientists have more publications than theoretical scientists (Hargens, 1975). Journal acceptance rates of papers and coauthorship patterns often vary by field. Astrophysics papers sometimes include 100 coauthors. Such a publishing pattern makes scientists who are engaged in these projects more likely to have a higher number of publications. The works of computer scientists are often published in their conference proceedings rather than in the journals. As Lewis and Gregorio (1981) confirmed, the number of journals in the discipline influences the number of publications for the individual scientists in the discipline.



* Note: (1) Solid lines represent a positive relationship; dotted lines a negative relationship. (2) Fields are controlled.

Figure 1. Relationship among collaboration, grants, and productivity

4.3 Summary and evaluation of the model

The framework with which to address and study differences in foreign-born scientists' collaboration, grants, and productivity consists of three stages. The first stage of analysis focuses on detailed descriptions of collaboration, grants, and productivity by using multiple indicators such as number of collaborators, collaborative work time, collaboration motivation, coauthors, cosmopolitan scale, current grants, first grants, grant sources, normal and fractional count productivity [see the measurements in Section 5.5].

The second stage of analysis deals with the impact of "being a foreign-born scientist" on collaboration, grants, and productivity. For this, the analysis identifies variables that are important for research collaboration, grants, and productivity. As shown in Figure 1, the major exogenous variables include being foreign-born, career age, gender, departmental quality, research preference, discrimination, research preference, mobility, cosmopolitan scale, center affiliation, job satisfaction, spouse's job, non-academic job experience, and field. Collaboration, grants, and productivity have common determinants such as being foreign-born, career age, gender, departmental quality, research preference, and discrimination. However, each of the three endogenous variables has its unique relationship with some of the exogenous variables such as cosmopolitan scale, mobility, center affiliation, job satisfaction, spouse's job, and non-academic job experience. In all the equations, field is used as a control variable.

In the third stage, the analysis focuses on what factors are more important in determining the collaboration, grants, and productivity of foreign-born scientists, compared to the factors that affect the collaboration, grants, and productivity of native-born scientists.

The model includes important factors in collaboration, grants, and productivity, especially regarding foreign-born scientists. However, two weaknesses are noteworthy. One is that endogenous relationships among the exogenous variables may exist. For example, being foreign-born might cause job satisfaction and motivation rather than the three variables being understood exogenously. Although the framework is designed to elucidate an independent effect of being foreign-born with controlling other variables, rather than to focus on causal impact of foreign-born on any of these potential endogenous variables, ideally it might need to readdress the issue. The other weakness is that the model might lack controls for career patterns and experiences that include past affiliation with certain organizations or sectors, post-doc experiences, and mentor relationships.

CHAPTER 5

DATA, MEASUREMENTS, AND METHODS

This chapter presents the data, measurements, and methods that this study uses. Section 5.1 and 5.2 present the data and the sample. Section 5.3 discusses the characteristics and limitations of the sample. Section 5.4, 5.5, and 5.6 deal with the indicators and measurement issues. These sections define foreign-born scientists, develop indicators for collaboration, grants, and productivity, and also discuss the measurements for the exogenous variables. Section 5.7 discusses the statistical methods. Finally Section 5.8 summarizes the chapter.

5.1 Data

The data for this study are RVM[22] Curriculum Vitae (CV) and 2001 RVM Survey, *Study of Careers of Scientists and Engineers.* The RVM CV data has 1,370 samples from university professors and researchers who are affiliated with NSF and DOE centers in U.S. universities [see Appendix B for the detailed description of sample selection]. CVs were solicited by e-mail in 2000 through NSF and DOE research centers.[23] The NSF website includes all of the centers. The website also provides each center's home page. NSF centers were divided into four main categories such as Engineering Research Centers (ERCs), Industry/University Cooperative Research

---

[22] RVM stands for Research Value Mapping Program, a research project supported by NSF and DOE. It is located in the School of Public Policy at the Georgia Institute of Technology, Atlanta, Ga.

[23] Detailed information on CV collection, coding, and cleaning procedures are provided in the works of Dietz (Dietz et al, 2000; Dietz, 2004)

Centers (I/UCRCs), State/Industry Cooperative Research Centers (S/IUCRCs), and Science and Technology Centers (STCs). Each center's home page contained a list of the faculty with basic information such as the e-mail address, telephone number, affiliation, and mailing address. Everyone on the faculty list was chosen as a potential respondent, and the RVM team sent e-mails to all of them to request CVs. Three follow-up e-mails were sent to those who did not respond initially. E-mail requests were sent to 3,814 scientists and engineers, and 1, 370 valid CVs were received. The overall response rate was 39% [See Appendix C]. The CV data include 3,000 variables of demographic data, degree data, job data, publication data, patent data, professional affiliation data, and grant award data.

The RVM *Survey of Careers of Scientists and Engineers* [see Appendix D] was conducted from October 2001 to March 2002. The survey was sent to 997 university faculty members from the RVM CV data who are not retired professors and industrial researchers. The survey was mailed to the faculty members after two pre-notice e-mails had been sent, and three reminder e-mails were sent to those who did not respond. The response rate was 44%, which means 443 returns. The survey includes questions about research collaboration, grants and contracts, job selection and work environment, research motivation, and demographic information.

After coding and cleaning the survey data, the CV data were combined into the survey data. Demographic, grants, educational background, citizenship, and national origin information from both dataset were cross-checked to confirm the identity and to update the data. In this process, some missing information of national origin and educational background was updated by searching the respondents' current websites where most of them maintain their updated CVs. Data on publications after the survey period [2001-2003] were collected from ISI's *Web of Science* and combined with the whole data set (see Section 5.4.3 for a detailed description of the collection of publication data).

5.2 Sample Description

Since the RVM Program designed its data collection to include all the scientists in the research centers, meeting the grantors' (NSF and DOE) needs, the sample is cross-disciplinary. This is especially true for the research centers included in the study; they are interdisciplinary-focused, mission-driven, and located mostly in elite research universities.

Among the survey respondents, 41% (181) are engineering professors; 15% (66) are bioscience professors; 5.6% (25) are computer science professors; 10.61% (47) are chemistry professors; and 9.7% (43) are physics professors. The remaining 12.9% (57) are professors in other fields of science.

Categorized by rank and gender, 62.8% (278) are tenured faculty; 37.2% (165) are nontenured faculty; 86.5% (383) are males; and 13.1% (58) are females.

In terms of national origin, 68.4% (303) are native-born scientists, and 31.4% (139) are foreign-born. Compared to national statistics, foreign-born scientists are slightly overrepresented in the sample and females are slightly underrepresented.[24] The average age of the respondents was 46 in 2000.

[24] In universities and four-year colleges, 22.2 percent of the science faculty are female and 20.4 percent of the science and engineering faculty are foreign-born (NSF, 2002)

As shown in Table 6 in the Appendix A, 56 % (79) of the scientists in the sample came from Europe and Canada, whereas 36 % (50) came from Asian countries. Only 8 scientists came from countries outside of Asia, Canada, and Europe. India, with 12.2 % (17 scientists), was the largest source of foreign-born scientists followed by China with 10.8 % (15), the United Kingdom with 10 % (14), and Germany with 7 % (10).

Table 7 shows where the scientists in the sample were born and where they earned their undergraduate and doctoral degrees. Foreign-born and foreign bachelor's degrees account for 25.5 % (113); 66.8 % (296) are U.S.-born and hold U.S. bachelor's degrees. Only 5.2 % (23) are foreign-born and hold U.S. bachelor's degrees. Only 9 % (40) of the doctorates in the sample were granted by foreign institutions; 85.6 % (379) came from U.S. institutions. Foreign-born scientists who hold U.S. doctorates are 20.9 % (93) of the sample, and 8.4 % (37) of the foreign-born also held doctorates from non-U.S. institutions. U.S.-born scientists who also hold doctorates from U.S. institutions are 65.2 % (286) of the sample.

Foreign-born and U.S.-born scientists are present in about similar proportion in most disciplines (Table 8). However, sharp departures from this equivalency appear in two fields, computer science in which foreign-born scientists are disproportionately represented, and biological/life sciences in which U.S.-born scientists significantly outnumber their foreign-born colleagues.

Table 9 shows the academic rank of the scientists. While 32.4 % (44) of the foreign-born scientists and 40.7 % (125) of the U.S.-born scientists are full professors[25],

[25] According to NSF's *Women, Minorities, Persons with Disabilities in Science and Engineering in 1994*, foreign-born doctoral scientists and engineers are less likely to be full professors or to have tenure. Among the native-born, 44 percent are full professors and 70 percent are tenured. The corresponding figures for the foreign-born are 38 percent and 60 percent.

27.9 % (38) of the foreign-born and 25.7 % (79) of the U.S.-born scientists are assistant professors; 19.9 % (27) of the foreign-born scientists and 15.6 % (48) of the U.S.-born scientists are associate professors.

In the gender, the foreign-born scientists are mostly male (91 %, 124); 84 % (259) of the U.S.-born scientists are male.

5.3 Sample characteristics and limitations

An ideal sample would be drawn from the total population of the scientists in U.S. academe without any sampling and coverage error. In particular, such an ideal sample would require random and proportionate selection of foreign-born scientists and native-born scientists from various clusters. However, the sample used for this study is drawn from those who are affiliated with university research centers. For this reason, members of the sample may have more grant opportunities than the general population of academic scientists because the centers are supported heavily by the government (e.g., NSF and DOE) and industrial research and development. Also, scientists in the sample may be more collaborative and productive than nonaffiliated scientists because of the relatively large staff-pool and resources in the centers. In this sense, the sample may be biased toward more collaboration, more grants, and higher productivity compared with the general population of academic scientists.

Another issue is whether the sample proportionally represents the population of foreign-born and native-born scientists in the U.S. academe, and even in the university research centers. The ratio of foreign-born scientists varies by field and institution. In terms of targeting the general population of academic scientists, the sampling would be much complex than we assume. This study was not intended to target the general population and instead focused on those who are affiliated with research centers. In the initial CV collection, the RVM requested CVs of all the scientists affiliated with the NSF research centers, regardless of their citizenship. Such a census nature of the sampling for the center-affiliated scientists provides an appropriate representation of foreign-born scientists in these organizations. Based on the limitation of the sample, the data results should be carefully interpreted.

5.4 Definition of foreign-born and native-born scientists

5.4.1 Foreign-born and foreign-educated

This study relies on the definition of those who were born and earned bachelor's degree in foreign countries. This definition has three advantages. First, data are more available. As is often seen in the documentation of personal information such as the curricula vitae of scientists, information on educational background generally excludes education earlier than a bachelor's degree (See the analysis in Dietz et al., 2000). In this case, where one got her or his bachelor's degree could be the basic distinction between those who graduated from an American college and those who graduated elsewhere. Second, the definition makes the comparison of native-born and foreign-born scientists more representative because the majority of foreign-born scientists come to the United States after finishing their bachelor's degree in their home countries. Third, the definition appropriately reflects the important differences between those who came to the United States before they finished their bachelors' degree and those who came after receiving their bachelors' degree. Because of their longer residency in the United States, the former usually are more accustomed to U.S. culture and have greater English proficiency than the latter group. Since undergraduate education is more of a socializing experience for a foreigner than a typical graduate education (North, 1995, p. 73), those who came at an early age may differ from the late comers.

5.4.2 Category of foreign-born scientists

In terms of differentiating foreign-born scientists, this study categorizes them into three groups: (1) those scientists who came from the least advantageous countries, neither Western culture nor English-speaking (FBFB0), (2) those who came from less advantageous countries, either Western culture or English-speaking (FBFB1), and (3) those who came from the most advantageous countries, Western culture and English-speaking (FBFB2). This categorization is based on the Chiswick & Miller Index and the Hofstede Composite Index [see Table 3 and the note in the Appendix Table 1].

Table 4. Category of foreign-born scientists

Category	Country of Origin
FBFB0	China, Japan, Korea, Taiwan, Egypt, Iran, Turkey, Venezuela, Mexico
FBFB1	Belgium, Czech, Denmark, France, Germany, Greece, India, Italy, Netherlands Poland, Portugal, Romania, Russia, Slovenia, Spain, Switzerland
FBFB2	Australia, Canada, Ireland, New Zealand, United Kingdom

5.4.3 Native-born scientists

The definition of native-born scientists in the analysis is those who were born in the United States and earned their bachelor's degree in the United States. Therefore, those who earned their bachelor's degree in a foreign country are excluded.

5.5 Measures for collaboration, grants, and productivity

Collaboration, grants, and productivity could be measured in various ways. This section develops the indicators that improve validity and rely on multiple indicators instead of single ones.

5.5.1 Collaboration

Many studies simply measure collaboration by the number of coauthors during a given time period. This method has several advantages such as (1) invariant, (2) easily and inexpensively ascertainable, (3) quantifiable, and (4) nonreactive (i.e. the process of ascertaining collaboration does not affect the process of collaboration itself) (Subramanyam, 1983; Ajiferuke et al., 1988). However, Katz and Martin (1997) question the validity of the use of the number of coauthors as a measure of collaboration. They point out several instances in which coauthors hardly meet the meaning of collaboration: (1) Two researchers work closely together but then decide to publish their results separately. (2) Researchers who have not worked together in their research nevertheless decide to pool their findings and write them up jointly. (3) Not all the institutional affiliations (often in the case of international collaboration) of coauthors are provided in the journals. Owing to these problems, they recommend that the level or intensity of "joint work" should be above a certain minimum threshold for it to constitute collaboration.[26]

One solution to deal with the weakness of coauthorship as a measure of collaboration is to count the number of collaborators who are actually working together for achieving the common goal of producing new scientific knowledge (Katz and Martin, 1997). By using a self-reported number of collaborators, important collaboration that did not involve publication could be included, and coauthors could be excluded who achieved that status not by virtue of collaboration but only because of their position.

With the self-reported number of collaborators as the main indicator for collaboration, this study also uses several relevant indicators that may represent a part of collaboration and at the same time affect the level of collaboration. These include collaboration motives, research time to collaborate, cosmopolitan scale (quasi-geographical dispersion of collaboration), and the coauthorship pool. By using the several indicators together, differences between foreign-born and native-born scientists are expected to provide a rich description of collaboration beyond the simple number of collaborators.

- *Number of collaborators*: The survey asked the respondents how many research collaborators they have had over the past twelve months. Research collaboration was

[26] Katz and Martin propose putative criteria for the concept of collaboration: (1) Those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contribution; (2) Those whose names or posts appear in the original research proposal; (3) Those responsible for one or more of the main elements of the research (e.g., the experimental design, construction of research equipment, execution of the experiment, analysis and interpretation of the data writing up the results in a paper); (4) Those responsible for a key step (e.g., the original idea or hypothesis, the theoretical interpretation); (5) The original project proposer and/or fund-raiser, even if his or her main contribution subsequently is management of the research (e.g. team leader) rather than research per se (p. 7-8).

defined in the question as "working closely with others to produce new scientific knowledge or technology." The survey measures the number of collaborators based on six categories: male university faculty, male graduate students, male researchers who are not university faculty or students, female university faculty, female graduate students, and female researchers who are not university faculty or students.

- *Collaboration motives*: The survey has thirteen items for collaboration motivation. It asked the respondents to evaluate the importance of each factor in the decision to collaborate.

  M1: Length of time I have known the person
  M2: Responding to requests of my administrative superiors
  M3: Interest in helping junior colleagues
  M4: Desire to work with researchers who have strong scientific reputations
  M5: Desire to work with researchers whose work skills and knowledge complement my own (rather than overlap with my skills)
  M6: Quality and value of my previous collaborations with the person
  M7: Interest in helping graduate students
  M8: The extent to which working with the individual is fun or entertaining (apart from the work itself)
  M9: Desire that the collaborator be highly fluent in my language
  M10: Desire to work with researchers from the same country of origin
  M11: The collaborator should have a strong work ethic
  M12: The ability of the collaborator to stick to a schedule
  M13: Practices for assigning credit (e.g. order of authorship)

  The responses were coded as 4 (very important), 3 (somewhat important), 2 (somewhat unimportant), and 1 (not important) for each item.

- *Research time for collaboration*: Research time for collaboration is an important indicator to show how much of her time a scientist actually spends working with collaborators at the different levels of organizations. The questionnaire asked the respondents to estimate the percentage of research-related work time devoted to each of the following categories over the past twelve months.

T1: Working alone (on research that at no point includes a collaborator)
T2: Working with researchers and graduate students in my immediate work group or laboratory
T3: Working with researchers in my university, but outside my immediate work group
T4: Working with researchers who reside in nations other than the United States
T5: Working with researchers in U. S. universities other than my own
T6: Working with researchers in U. S. industry
T7: Working with researchers in U. S. government laboratories.

- *Cosmopolitan scale of collaboration*: There are various types of collaboration: local, interdepartmental, inter-institutional, or international. In comparing the collaboration activities of foreign-born and native-born scientists, an interesting question is whether foreign-born scientists are more cosmopolitan than native-born scientists. Since foreign-born scientists were born and educated in foreign countries – some of them even have job experiences outside the United States, it could be reasonably expected that the collaboration of foreign-born scientists is more cosmopolitan. The scale was calculated by multiplying the fraction of his or her time that each participant spent working with a type of collaborator by the cosmopolitan rank of that variable (measured on a 0 to 5 scale). "Research time spent working alone" is given a value of 0 on the cosmopolitan scale. Similarly, "research time spent working with members of the same work group" is assigned a 1 and "time spent working with others in the same university, but a different work group" is assigned a value of 2. "Working with researchers at a different university" counts as a 3 on the cosmopolitan scale and "working with others in industry or government laboratories" are both assigned a value of 4. Lastly, "working with researchers in other nations" counts as a 5 on the cosmopolitan scale. For instance, if I work alone 10% of the time, within my own work group 20% of the time, with scholars at other universities 30% of the time, with industry 10% of the time, government 10% of the time and with scholars at other nations 20% of the time, my cosmopolitan score would be 2.6 (i.e., 0.1(0) + 0.2(1) + 0.3(2) + 0.1(4) + 0.1(4) + 0.2(5)).

- *Coauthorship pool*: Although the number of coauthors has weaknesses in measuring collaboration, it could present a certain level of collaboration in terms of publication-oriented collaboration. It is hard to measure the coauthorship pool by a survey method because it evolves over a long career, and it is sometimes hard to count without missing past coauthors. A better option is to use the scientists' curricula vitae, which include detailed publication information. For this study, all coauthors for each of the respondents were counted without duplication. The counting process presented some difficulties. First, a few CVs do not include the coauthors' names of published articles. In these cases, the article was researched on the *ISI Web of Science*. Second, a few CVs use a very minimal format for authors' names, listing only the last name and a first initial. The *Web of Science* was also searched in these few cases in an effort to avoid duplication of names. This problem of first initials and surnames was particularly acute with Asian scholars (e.g., Chinese and Korean scientists) because many have similar last names (e.g., Li, Lee, Kim, Zhou, Zang, Jang, Chen, Cheng, Yang, etc), and having only a first initial complicates distinguishing among them.

5.5.2 Grants

The amount of grants is most often used as an indicator for grant activity and research resources. Although the concept of grant and grant amount is commonly shared among scientists, it does not perfectly reflect grant activity. Grant amount sometimes reflects the nature of research rather than how much a scientist actively pursues grants and how favorably his or her research is regarded. In some studies, a dummy variable to distinguish those who have grants from those who do not is used as an indicator of grant activity (Godin, 2003). Such a technique, though, is inadequate for comparing scientists in science and engineering at research universities because most of them have one or more grants. Similarly, the total number of grants may not show very well how much a scientist has been engaged in grant-getting activity, since some scientists have many small grants but some other scientists have very few big grants. It may depend on the discipline.

In recognition of the difficulty of measuring grant activity, this study uses an alternative concept designated as grant intensity in which the current total grant amount is divided by its year(s) of duration. By using the annual average of the grant amount, this method could, to some extent, reduce the total amount of difference that arises among grants because of the differences in the nature of research in various fields. In particular, this study examines not only the amount of current grants but also career first grants, number of career grants, grant sources, duration, and proposal acceptance rate (batting average) so as to provide detailed descriptions of grant differences. First grants often play an important role in career development. Because early career scientists, mostly postdocs and assistant professors, generally have fewer resources than established scientists, being awarded a grant often makes a significant difference (Godin, 2003). Grant source also is expected to show how foreign-born scientists and native-born scientists rely on different sector of grantors for their research funds. Similarly, the number of proposals and the number of accepted proposals may indicate how actively and successfully a scientist has engaged in grant activity.

- *Dollar amount of current grants* (used as log transformation): Research grants as PI or CO-PI between 2000 and 2001
- *Grant duration:* The number of years of duration of current grants
- *Grant sources*: Grantor organizations
- *Number of career grants:* Total number of career grants as PI or CO-PI
- *Number of proposal submitted and accepted (batting average)*: The number of grants proposals submitted and accepted over a career. [27]
- *First research grants:* Career-first research grants as PI or CO-PI
- *Time lag for the first grants*: The number of years between first grants as a PI (or Co-PI) and obtaining doctorate.

5.5.3 Productivity

Because of the data complexity, it is rare to use multiple indicators at the same time in studies of publication productivity. A simple number of publications is most

[27] Reporting the number of submitted and awarded proposals might be inaccurate because senior scientists may not remember the exact numbers of proposals. Particularly, the number of submitted proposals might be more vulnerable to a memory problem. However, by randomly choosing 20 CVs and survey responses, this study compared the number of awards in the CV and in the survey. Among them, 16 CVs and surveys have the same number of awards. This means that a problem with recall may be not be a serious issue in this case.

frequently used as an indicator for publication productivity. This study goes further on publication productivity by using two different counts, normal and fractional. The normal count is the number of refereed scientific articles. It allows equal treatment for each author, which results in giving a full credit to each of the authors regardless of who happens to be the first or the last author. A problem with the normal count is that in most cases there is no reason to expect that coauthors contributed equally. Hagstrom (1965) found evidence that some publications listed authors for purely social reasons. More recently, LaFollette (1992) found that the practice of making colleagues "honorary coauthors" has become quite common.

In contrast, in a fraction count each item in a multiple-authored paper is divided by the number of authors and then summed to one. Narin (1976) argues that there does not seem to be any reasonable way to deal with the attribution problem except to attribute a fraction of a publication to each of the authors. Lindsey (1980) vindicates the advantage of a fractional count, pointing out that it can control for bias in overestimating production when the full value of a coauthored paper is awarded to all contributors. The main weakness of the fractional count, however, is that the procedure is tedious.

Normal count = N

$$\text{Fractional count} = \sum_{j=1}^{k} (1/j)(F_j/N)$$

F_j = the number of j authored research papers

N = the total number of the author's papers

K= the greatest number of authors per paper

By using a normal and a fractional count at the same time, this study intends to do a more robust test for publication productivity. The publication records of each respondent in the sample were traced in the *Science Citation Index Expanded (SCI-EXPANDED)* through the *ISI Web of Science. SCI-EXPANDED* covers more than 3,300 journals from more than 100 scientific disciplines. The authors were identified by matching the name, department, and institution from the CV-survey data and the SCI data. SCI provides all of the coauthors' names, departments, institutions, and addresses. For a simple count (normal count), the entire peer-reviewed journal articles between 2001 and 2003 were counted for each respondent. For the fractional count, each article was divided by the number of coauthors. However, the data do not allow having a weighted measure of publication because the sample came from several disciplines, not from one specific discipline. Nor do the data permit quality comparisons among the journals or impact ratings. Including quality-based indicators (such as citations and journal impact factors) in a pilot study indicated that doing so for the thousands of journal publications in the current data set would be prohibitively expensive in time and resources

- *Publication counts (normal count and fractional count) before the survey*: All peer-reviewed journal articles between 1996 and 2000 were counted before the survey. Producing the average publication count, the total number of publications was divided by five or the number of years for those who obtained their doctoral degree after 1996.

- *Publication counts (normal count and fractional count) after the survey*: All peer-reviewed journal articles between 2001 and 2003 were counted after the survey. The average publication count was created by dividing the total number of publication count by three.
- *Career average of publication count*: After all peer-reviewed journal articles were counted, the total number of publications was divided by the number of years since the author's doctoral degree.

5.6 Measures for the other variables

- *Career age*: This study uses career age as a proxy of age and rank. It is measured by the number of years since a doctorate was received.

- *Departmental rank*: This is based on National Research Council data ("*Research-Doctorate Programs in the United States Continuity and Change, 1995*"). The ranking scores are a composite of educational quality, faculty reputation and activity, funding measures, program size measures, and program composition measures. Relying on the total scores, 1= top 25, 0= otherwise.

- *Research motivation (preference)*: Composite score based on two items ("my scientific work is the most important thing in my life" and "there is nothing as satisfying as doing the best science possible"). The inter-item reliability (Alpha) is .6371. The items were measured by 4-Likert scales (4 = strong agree, 3=somewhat agree, 2= somewhat disagree, and 1= disagree).

- *Perceived discrimination*: Perceived discrimination is measured by the question item, “At my current institution, I am discriminated against on the basis of my race, ethnicity, religion, or national origin.” The items were measured by 4-Likert scales (4 = strong agree, 3=somewhat agree, 2= somewhat disagree, and 1= disagree).

- *Job mobility*: The career average number of job changes from institution to institution after a doctoral degree. It does not count a change within the organization (e.g., rank change or administrative positions in different academic units within the same institution)

- *Research center*: Scientists’ affiliation with the centers was coded as “1” for ERCs and “0” for I/UCRCs, S/IUCRCs, STC, and DOE centers, because ERCs have, on average, more research grants than other types of centers (Roessner, 2000)[28].

- *Job satisfaction*: Three items in the survey address job satisfaction in the research environment: “I am satisfied with my job,” “My colleagues in this department appreciate my research contributions,” and “I think I am paid about what I am worth in the academic market.” Measuring faculty job satisfaction often consists of three elements such as general feeling about the job,

[28] Although matching funds from industry and state governments account for a substantial portion of the R&D for the centers, ERCs still have more R&D funds than others (Roessner, 2000)

appreciation from others, and satisfaction with salary or reward (Blackburn and Lawrence, 2003). The inter-item reliability (Cronbach Alpha) of these items is .548, indicating that the set of items is acceptable for measuring job satisfaction with a single dimension.

- *Spouse job:* Anyone whose spouse is a full-time homemaker is coded "1," otherwise "0".

- *Nonacademic job experiences*: It is coded "1" for those who have had job experiences in industry or government since doctoral degree. "0" for otherwise.

- *Field:* Controlling a field effect is an important issue in this study. Based on the closeness of research activity and publication pattern, this study divides the disciplines into four groups: engineering, physical sciences (physics and chemistry), life sciences and biology, and math and computer sciences. The categorization is also largely consistent with that of NSF *Science and Engineering Indicators*.[29]

5.7 Methods

This study uses ANOVA and structural equation modeling (SEM) to test the hypotheses. As shown in Figure 2, the group of scientists is divided into two: native-born

[29] NSF *Science and Engineering Indicators* (2004) use physical sciences, mathematics, computer sciences, earth/atmospheric/ocean sciences, life sciences, psychology, social sciences, engineering as the field category. The justification for this categorization is not explained.

and foreign-born scientists. The foreign-born scientists are also divided into scientists who came from the most advantageous countries (FBFB2), the less advantageous countries (FBFB1), and the least advantageous countries (FBFB0), depending on the cultural and language distance. This scheme requires an analysis of within- and between-group differences by focusing on the questions: (1) Are these groups different from each other? (2) If so, which group is the most different?

While ANOVA deals with simple comparison of the group means, SEM is employed for examining the reciprocal relationship among collaboration, grants, and productivity. As presented in Chapter 4, the three components cannot be properly analyzed without considering simultaneous and nonrecursive relationships among them. This study uses maximum likelihood (ML) under the SEM. Particularly, ML allows model-implied correlations between endogenous variables and the disturbances of subsequent variables the endogenous variables are specified to affect. For this reason, ML estimation is appropriate for nonrecursive path models (Kline, 1998). Detail applications of SEM for this study are provided in the Appendix E Technical Note.

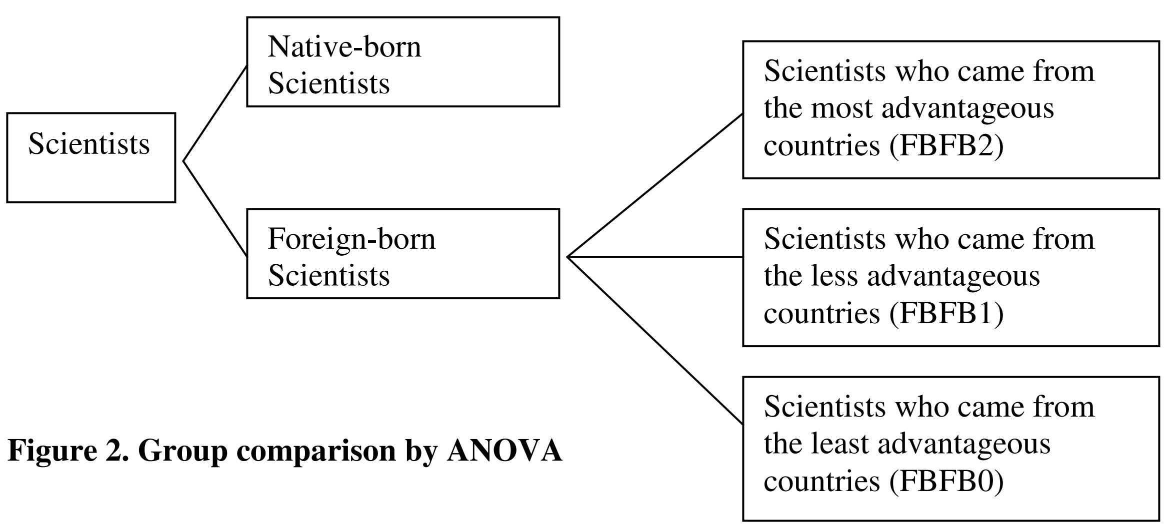


Figure 2. Group comparison by ANOVA

5.8 Summary of the chapter

This chapter covered various issues of data, sample, indicators, and methods. This study uses the RVM CVs and survey data that have 443 scientists who are affiliated with NSF or DOE university research centers. Among them, foreign-born scientists are 136 (31%). Foreign-born and native-born scientists are distributed in a similar proportion over the disciplines.

This study defines foreign-born scientists as those who were foreign-born and foreign-educated until their bachelor's degrees because foreign-born scientists in this category are most prevalent among the foreign-born scientists in the United States

Multiple indicators are developed for providing detailed description of collaboration, grants, and productivity. Number of collaborators, collaboration motives, collaborative research time, and a cosmopolitan scale are used for describing the differences in research collaboration. In terms of grants activity, the analysis will use current, first, and career total and average grants, grant sources, batting average, and the time lag between receiving a doctoral degree and receiving a first grant as PI or CO-PI. Publication differences will be described by normal and fractional counts of peer-reviewed journal counts in the categories of career average, the five years (1996-2000) before the survey, and the post-survey period (2001-2003).

This chapter also provides measures for the independent variables such as career age, gender, departmental quality, research motivation (preference), perceived discrimination, center affiliation, job mobility, job satisfaction, spouse's job, nonacademic job experiences, and field [see the summary in Table 10 in the Appendix A].

For dealing with the group differences and the reciprocal relationship among collaboration, grants, and productivity, this study uses ANOVA and structural equation modeling (SEM).

CHAPTER 6

FINDINGS

This chapter presents the findings. The first four sections (Section 6.1 through 6.4) report the findings about the differences in collaboration, grants, productivity, and other import variables. The last two sections (Section 6.5 and 6.6) report the findings about the independent effect of being foreign-born and the structural differences of foreign and native-born scientists.

6.1. Research collaboration of foreign-born scientists

To analyze the difference in research collaboration, several relevant indicators have been included such as number of collaborators, collaboration motives, collaborative research time, cosmopolitanism, and coauthorship. These indicators may represent a part of collaboration and also affect the level of collaboration.

6.1.1 Number of collaborators

As the most important measure of collaboration, the survey asked the respondents the number of people with whom they had collaborated over the past twelve months. On average, the scientists in the sample collaborated with about fourteen people. As shown in Table 11, the native-born scientists had slightly more collaborators (14.04) than the foreign-born scientists (13.78), but not enough more to be statistically significant ($p > .3$). In most categories, the differences amount to less than one person. The native-born scientists have more collaborators with male faculty members, non-university male researchers, female faculty members, and female graduate students, but the foreign-born scientists have more collaborators in male graduate students.

The only significant difference is found in the ratio of female collaborators. Native-born scientists have a higher ratio of female collaborators (0.28) than their foreign-born counterparts (0.23). As research collaborators, female graduate students are more likely to be associated with native-born scientists than with foreign-born scientists. Regardless of which group one addresses, however, scientists generally have, on average, many more male collaborators (10.27) than female collaborators (3.76). The ratio of faculty in the total number of collaborators does not significantly exceed that of students. In other words, almost half of the collaborators are graduate students. The result also indicates that almost 82 % of the collaborators are working in their own work group.

In the meantime, those who came from the least advantageous countries (FBFB0) such as China, Japan, Korea, and Middle East countries surprisingly have more collaborators in most categories than any other group. Although the differences are not statistically significant,[30] this finding implies that the number of collaborators might not be seriously affected by foreign-born scientists' particularistic characteristics.

Regardless of their discipline[31], foreign-born and native-born scientists are much alike in the number of collaborators (Table 12). In engineering, foreign-born scientists and native-born scientists have, on average, 15.14 and 15.50 collaborators, respectively. But native-born scientists in the physical sciences and biology-life sciences surpass foreign-born scientists in the number of their collaborators.

---

[30] As a caveat, the statistical significance seems less reliable because this study has only a small number (e.g., FBFB0 are only 35) of samples for each group.
[31] Because of the small size of the sample, the test for disciplinary differences was not based on the three FBFB categories.

6.1.2 Collaboration motivations

The survey has thirteen items for collaboration motivation. It asked the respondents to evaluate the importance of each factor in the decision to collaborate. Table 13 shows that foreign-born scientists are significantly different from native-born scientists in some motivations to collaborate such as M3 (interest in helping junior colleagues), M8 (fun or entertaining), M9 (desire that collaborator be highly fluent in my language), M10 (desire to work with researchers from the same country of origin), and M11 (the collaborator should have a strong work ethic). In the decision to collaborate, foreign-born scientists are less likely to be influenced by a desire to help junior colleagues. Likewise, motivations of fun/entertainment (M8) and possession of a strong work ethic (M11) are less important to foreign-born scientists than to native-born scientists. A bigger difference is found in motivations related to language and nationality. Although the respondents generally do not think that these conditions are important for collaboration, the native-born scientists are more likely than their foreign-born counterparts to assign importance to such qualities as speaking English fluently and being a U.S. citizen. Foreign-born scientists appear to ignore these qualities in their collaboration. Since the United States is not their home country, these motivations have little effect on their collaboration decisions. If they insisted on collaborating only with those who speak their native language and who have the same national origin, their level of collaboration would be substantially limited.

Some differences are also found among the foreign-born scientists (FBFBs). Those who came from the most advantageous countries in terms of language and culture (FBFB2) are most likely to be motivated to help junior colleagues, whereas those who came from the less advantaged countries (FBFB1) are least likely to be. In terms of fun/entertainment, those who came from the least advantageous countries (FBFB0) are least likely to be motivated to collaborate. However, no significant difference in language, nationality, and work ethic occurs among the foreign-born scientists.

Table 13 also shows that scientists' collaborations are more likely to be motivated by practical reasons like the complementary skills of collaborators, the quality of collaborators, strong scientific reputations, a strong work ethic, and being able to stick to a schedule than by other reasons. This finding is consistent with Melin's study (2002). These items have relatively higher measures than the other items in the survey. In these motives for collaboration, there is no significant difference between or within the groups.

6.1.3 Research time for collaboration

Research time for collaboration is an important indicator to show how much of her time a scientist actually spends on working with collaborators at the different level of organizations. The questionnaire asked the respondents to estimate the percentage of research-related work time devoted to each of the several categories for the past twelve months.

As shown in Table 14, the foreign-born scientists are more likely to be isolated from collaborative activity than the native-born scientists are. They spend 22 % of their research time working alone compared with 14 % for the native-born scientists. Both FBFB1 and FBFB0 are much more likely to be working alone than are FBFB2 and the native-born scientists. Compared with foreign-born scientists, native-born scientists spend substantially more time working with researchers in U.S. universities other than the scientist's own university. While native-born scientists spend 9.8 % of their research time working with researchers in U.S. universities other than their own, FBFB0 and FBFB1 spend only 5.9 and 6.7 % of their time, respectively, in such a way. In terms of international collaboration, foreign-born scientists spend slightly more time than native-born scientists do, but not enough to be statistically significant. Native-born scientists spend more time than foreign-born scientists in collaborating with researchers in industry and government, but this result is not statistically significant either. The overall result indicates that native-born scientists spend more time in collaborative research than do foreign-born scientists, and that in both groups these scientists generally spend half of their research time working with people within their immediate work group.

6.1.4 Cosmopolitan scale

This study relies on the cosmopolitan scale that Bozeman and Corely (2004) previously developed for the same sample. As shown in Table 15, the results indicate that, contrary to initial expectations, native-born scientists are more likely to be cosmopolitan than foreign-born scientists are. Although FBFB2 have a higher cosmopolitan scale, FBFB1 and FBFB0 have a lower scale, which decreases the average of foreign-born scientists. Although foreign-born scientists collaborate more with researchers abroad than native-born scientists do, they also collaborate less with U.S. researchers outside of their own university. The result is a lower score on the cosmopolitan scale than for the native-born scientists. In terms of discipline (Table 16), although foreign-born scientists show a very similar scale in all fields, native-born scientists in computer sciences and physical sciences are more likely to be cosmopolitan in the geographical sense than those who are in engineering and biology-life sciences. The biology-life scientists score lowest on the cosmopolitan scale.

6.1.5 Coauthorship pool

Table 17 shows that native-born scientists generally have more coauthors than do foreign-born scientists. Native-born scientists have almost ten more coauthors than foreign-born scientists. But among the foreign-born scientists themselves, there is no significant difference. Although the career totals of native-born scientists show a difference, these results are not very convincing in identifying a difference between native-born and foreign-born scientists because foreign-born scientists are slightly more concentrated in assistant professorships, and less in full professorships. Surprisingly, the career average number of coauthors, the total coauthors divided by the career age, is a little higher for the foreign-born scientists than for the native-born scientists. Although this is not significant statistically, it implies that coauthorship has little to do with the scientists' citizenship. Table 18 shows the difference in disciplines in the coauthorship pool. There is no significant difference in the coauthorship pool between foreign-born and native-born scientists in each discipline. But differences exist across the disciplines themselves, with physical sciences having the most coauthors (3.99) and math and computer sciences having the fewest (2.35) coauthors.

6.2. Research grants of foreign-born scientists

This section describes grants activities including total grants, first grants, current grants, grant frequency, grant sources, and grant proposal acceptance rate.

6.2.1 Grant amount

As shown in Table 19, although there is no significant difference between the native-born scientists and the foreign-born scientists in research grant amounts, the foreign-born scientists have larger grant amounts in all the statistics such as mean, median, and career average. For non-normality reasons, the logarithm of grants is used for T-Test results. As the median grant total, the foreign-born scientists have about $3,910,000, whereas the native-born scientists have about $3,143,000. In the career average of grants, the grant total divided by the career age, foreign-born scientists have a larger grant amount. This could be attributed to differences in disciplines. As Table 20 shows, the scientists in computer sciences and engineering have, on average, a larger amount of grant money than biology-life sciences and the physical sciences. In particular, foreign-born scientists in computer science have much more grant money than native-born scientists in the same field. As a caveat again, this analysis should be treated carefully treated because of the small sample size of foreign-born scientists in each field of work.

The survey asked the respondents about the grant amount, duration, and source of first and current grants. Table 21 indicates that there is no significant difference in the first and current grant amounts between the native-born and foreign-born scientists. As the median, foreign-born and native-born scientists have current grants of $490,000 and $435,000, respectively. Foreign-born scientists also had a larger amount of first grants than their native-born counterparts. But among the foreign-born scientists, FBFB0 got lesser amounts in first grants than FBFB1 or FBFB2. However, FBFB0 have larger current grants than any other group. This result also implies that the status or characteristics of foreign-born scientists has little influence on grant activity.

Likewise, Table 22 shows that there is no significant difference between foreign-born and native-born scientists in each field but there is significant difference among fields. In terms of average grants, engineering has the largest amount of grants than other fields. ANOVA tested the differences based on the log transformation since the raw grants are seriously skewed.

6.2.2 Number of grants and grant sources

Although it is not clear whether different grant sources have different impacts on research activity and performance, it is important to examine what sources scientists rely on and whether foreign-born scientists are engaged differently with these types of sources. As the median number, scientists in the sample have had a total of 14 grants in their career; seven government grants, four industry grants, two nonprofit organization grants, and one foreign grant (Table 23). More foreign-born scientists than native-born scientists had grant awards from foreign sources and from nonprofit foundations. But no significantly different pattern was found in the number of grants by each source.

Table 24 shows that there is no significant difference in the sources of current grants between native-born and foreign-born scientists. For the scientists in the sample, the majority of grants were provided by government agencies, 79.4%, whereas only 20.6 % of the grants were awarded by industry and some private foundations, since the respondents in the sample are affiliated with the research centers that NSF and DOE support. No difference is found between foreign-born and native-born scientists. The

Pearson Chi-Square Test reports no significant difference with Chi-square value =.062, df=1, and Asymp.Sig (2-sided) =.803.

6.2.3 Grant proposals and awards

The number of research proposals submitted for grants reflects, to some extent, the researcher's grant activity. As Table 25 indicates, on average, over their careers, native-born scientists had 18 awards from 33 submitted proposals, whereas foreign-born scientists had 14 awards from 28 submitted proposals. Therefore, the batting average – the total number of awarded proposals divided by the total number of submitted proposals – is very similar between foreign-born (0.55) and native-born scientists (0.56). However, among the foreign-born scientists, FBFB0 produced more proposals than any other group, whereas FBFB1 produced significantly fewer proposals than the native-born scientists. FBFB0 have 20 awarded proposals, more than any other group. But FBFB1 have the fewest number of awarded proposals. Although it is not statistically significant, FBFB0 have a little higher batting average, 0.61, than other groups.

Table 26 shows the batting average differences among the fields. Biologists and life scientists have the highest batting average, 0.611, whereas computer scientists and mathematicians have a significantly lower batting average, 0.48. Except in biology-life sciences, foreign-born and native-born scientists have similar batting averages.

6.2.4 Time lag for career first grants

One interesting point in the grant difference is to see how early in their career foreign-born scientists obtain their first grants compared with native-born scientists. The foreign-born scientists wait longer than native-born scientists for their first grant after receiving their doctoral degrees. As shown in Table 27, on average, foreign-born scientists take 5.6 years to secure the first grants after their doctoral degree, whereas the native-born scientists succeed in 4.8 years. Among the foreign-born scientists, FBFB2 take more time to get their first grants than FBFB1 or FBFB0.

6.3. Research productivity of foreign-born scientists

Research productivity is measured by the number of peer-reviewed journal articles. As Table 28 shows, foreign-born scientists are significantly more productive in all categories than native-born scientists. First, in the career average, foreign-born scientists published about 3.7 journal articles every year since their doctoral degree, whereas native-born scientists have published slightly fewer (3.0). Among the foreign-born scientists, FBFB2 are more productive than FBFB1 and FBFB0. Second, in publication productivity for five recent years (1996-2000), foreign-born scientists are consistently more productive than native-born scientists in both the normal and fractional counts. During this time period, foreign-born scientists published 4.4 articles per year, whereas native-born scientists published 3.6 articles per year. FBFB2 were more productive in this time period than any other group. Third, the trend of publication productivity was maintained during 2001 and 2003. In this postsurvey time period, foreign-born scientists published on average almost one more article per year than native-born scientists. Among foreign-born scientists, FBFB0 were the most productive in both measures of publication.

Table 29 reports field differences of publishing productivity. There are statistically significant differences among the fields. Physical sciences (physics and chemistry in this sample) have consistently more publications in all categories such as career average, recent average (1996-2000), and postsurvey average (2001-2003). Physical scientists published, on average, four articles every year after their doctoral degree. Engineering and bio-life sciences have a similar number of publications in all categories. Computer science has the fewest number of publications, less than two articles per year. A post hoc test (Tukey HSD) shows that physical sciences are significantly different from all other fields and that engineering is different from computer sciences.

In each field, the differences between foreign-born and native-born scientists vary. In the engineering, foreign-born scientists published significantly more articles than native-born scientists across all categories. Foreign-born scientists published, on average, one more article than did native-born scientists in a simple count of publications. Even in the fractional count, the differences are still significant between foreign-born and native-born scientists. In the physical sciences, foreign-born scientists published slightly more than native-born scientists, but the differences are not significant at the 0.05 level. Likewise, the bio-life sciences do not show a significant difference between foreign-born and native-born scientists in any category. In the meantime, foreign-born scientists are significantly more productive than native-born scientists in computer science and mathematics. In publications of the same time period, normal and fractional counts do not yield different T-test results.

6.4. Differences in other variables

Table 30 shows the mean differences of other important variables. About 50 % of the scientists in the sample are affiliated with ERC. There is no significant difference among the groups. Foreign-born scientists are more committed to research than are native-born scientists; foreign-born scientists agree more that their scientific work is the most important thing in their life and agree more that there is nothing as satisfying as doing the best science possible. No significant difference is found among foreign-born scientists.

On the basis of race, ethnicity, and national origin, foreign-born scientists are more likely to perceive discrimination in their respective research environments. Among the foreign-born scientists, FBFB0 are most likely to feel that they are discriminated against. As a caveat, even though there is a significant difference between native-born and foreign-born scientists, the level of perceived discrimination is very small, meaning "somewhat disagree" about discrimination. Despite the single item measure, this finding indicates that foreign-born scientists, in fact, do not perceive discrimination as a major problem.

Scientists in the sample are generally satisfied with their jobs. They are more likely to think that they are satisfied with their job, and that their colleagues in the department appreciate their research contributions. No significant difference is found in these items. The table also shows the difference of job mobility. By the career average (total number of job changes after doctoral degree divided by the career age), foreign-born than native-born scientists move more frequently from institution to institution. The relatively larger proportion of full professor of native-born scientists probably reduces the level of average mobility since full professors may change their jobs less often than junior professors. About 26% of native-born scientists and 34% of foreign-born scientists are affiliated with ERC. About 46% of native-born scientist and 37% of foreign-born scientists ever had non-academic job experience since their doctoral degree. Interestingly, about 32 % of native-born scientists have a spouse who is a fulltime homemaker. This is significantly higher than that (23%) of foreign-born scientists.

6.5 Impact of being foreign-born on research activity and performance

The previous section described differences between foreign-born and native-born scientists in research collaboration, grants, and publishing productivity. While foreign-born scientists differ little from native-born scientists in research collaboration and grants, the groups differ significantly in publication productivity. Although foreign-born scientists are likely to spend more time working alone, they have more coauthors than do native-born scientists, and slightly fewer collaborators than do native-born scientists. In the meantime, native-born scientists have held jobs in more institutions and are more cosmopolitan than foreign-born scientists. Native-born scientists collaborate with more researchers outside their universities than do foreign-born scientists. In terms of grants, foreign-born scientists take longer to obtain their first grants after their doctorate degree. However, the two groups are similar in current grants. A consistently significant difference is found in publication productivity. In the average number of journal articles of career total, recent five years (1996-2000), and current three years (2001-2003), foreign-born scientists are more productive than their native-born counterparts in both normal and fractional counts.

Although this descriptive analysis shows critical evidence for the research hypotheses, this study intends to examine more fundamental questions articulated in Section 4.1. First, even if "being foreign-born and-educated (bachelor)" has a significant bivariate relationship with research activity and performance, particularly with publication productivity, is the relationship maintained once other relevant variables are controlled for? In other words, is any observed relationship an artifact of co-variation with other related variables? Second, given the factors, which factors do differently affect the level of collaboration, grants, and productivity between foreign-born and native-born scientists? In other words, the question addresses whether the research activity and performance of foreign-born scientists are determined in a way similar to the way those same traits are determined for native-born scientists.

The models that this section analyzes are modified from the original one in Figure 1 in Section 4.2, because there is a temporal sequence in research collaboration, grants, and productivity in the dataset. There are three time periods such as (1) before the survey period (1996 -2000; t_0), (2) during the survey period (2000-2001; t_1), and (3) the post-survey period (2001-2003; t_2). Collaboration (Ct_1) and grants (Gt_1) belong to the second time period (2000-2001), while productivity are divided into two – before the survey productivity (Pt_0) and the post-survey productivity (P_{t2}). As Figure 3 shows, the post-survey productivity (Pt_2) is determined by $Ct_{1,}$ $Gt_{1,}$ and $Pt_{0.}$ Foreign-born scientists are not divided into three groups in the later analysis because of the model complexity and relatively small sample size in each group.

Table 31 shows a descriptive statistics of all the variables in the models. The study uses the LISREL to apply SEM. The estimation is based on the Maximum Likelihood that is often used for over-identified models [see the technical note in Appendix E].

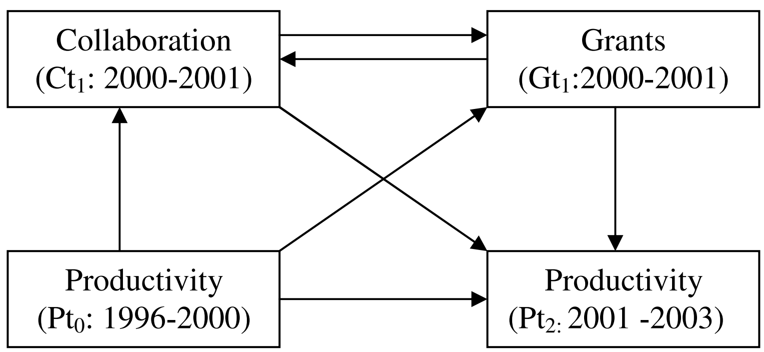


Figure 3. Modified relationship among collaboration, grants, and productivity

6.5.1 Collaboration

As shown in Figure 4 and Table 32 (productivity measured by the normal count) and 33 (productivity measured by the fractional count) and Figure 11 in the Appendix A, collaboration is significantly determined by productivity (Pt_0), research preference, cosmopolitan scale, engineering, and biology-life sciences. As about 30 % of productivity (Pt_0) increases, the number of collaborators increases, on average, approximately by one, controlling for the other variables. The magnitude of the productivity effect on the level of collaboration seems not so big in reality because such a large increase in the productivity of a single scientist is often unlikely. Research preference is strongly associated with the level of collaboration; the more research-motivated, the more engaged in collaboration. Likewise, cosmopolitanism has a strong positive effect on collaboration. For each additional scale increase, the number of collaborators increases by approximately seven persons. Relatively speaking, cosmopolitan scale has the strongest power to predict collaboration in terms of its beta weight, .379 in the normal count model (Figure 4). Although this relationship is not perfectly linear, it indicates the importance of the inter-institutional interaction is for research collaboration (Chompalov, 1999; Rogers, 2000).

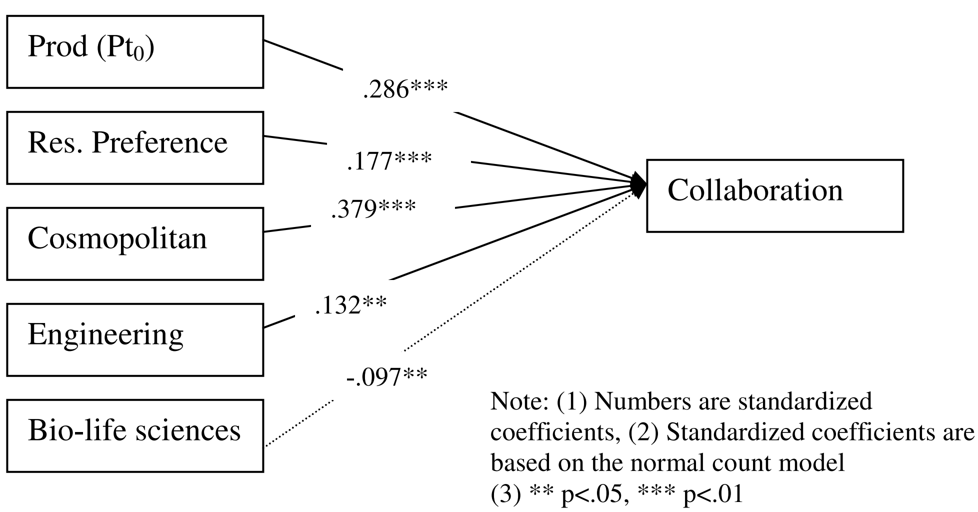


Figure 4. Determinants of collaboration

Four fields such as engineering, physical sciences, biology-life sciences, and computer science and mathematics were controlled for the model. Engineering has more collaborators, 2.44 in the normal count model and 2.31 in the fractional count model, than its reference group, *ceteris paribus*. But biology and life sciences have almost two collaborators fewer than other fields, controlling for other variables.

However, being foreign-born has no solid relationship with collaboration in the presence of other variables. It is only significant in the alpha level of .10. But the negative sign shows that foreign-born scientists have fewer collaborators than do their native-born counterparts.

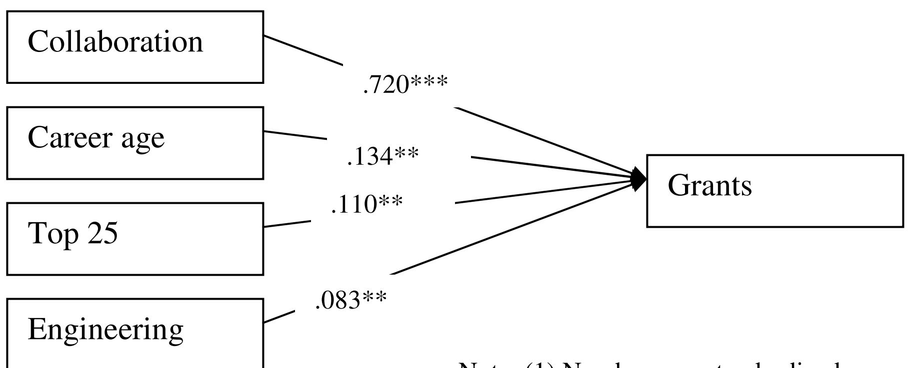
Grants do not have a statistically meaningful effect on collaboration. The direct effect may be suppressed by the reciprocal relationship between them. As shown in both tables 33 and 34, grants have a significant effect on collaboration in the opposite direction.

Contrary to general expectations in the literature, career age, gender, departmental quality (top25), discrimination, and mobility do not have any significant relationship with collaboration, when other variables are controlled for. Career age has only a marginal impact (.08) on collaboration.

In summary, any significant independent effect of being foreign-born is not found in research collaboration.

6.5.2 Grants

As indicated in Figure 5 and tables 32 and 33, collaboration, career age, departmental quality (Top 25), and engineering play significant roles in grants. Collaboration predicts grants better than any other variables in the model. It has the largest beta weight, .72 in the normal count model. Career age is also a significant variable in predicting grants. It may be influenced by the sample characteristics in which senior scientists who are more likely to be tenured faculty have more grants than junior faculty, other things being equal. On average, an increase in one year of career age results in about a seven percent increase in current grants, *ceteris paribus*. Departmental quality also is a significant predictor for grants. On average, the scientists in the top 25 have as large grants as about 120 % than those who in lesser ranked institutions, other variables being equal. Likewise, engineering has a larger dollar amount of grants than its reference group do, while biology-life sciences and math-computer sciences secure a smaller dollar amount of research grants.



Note: (1) Numbers are standardized coefficients, (2) Standardized coefficients are based on the normal count model
(3) ** p<.05, *** p<.01

Figure 5. Determinants of grants

Being foreign-born is only marginally significant in grants at the .10 alpha level; the dollar amount of grants awarded to foreign-born scientists is less than the amount secured by native-born scientists. Interestingly, those who more perceive discrimination in their research environment have a larger dollar amount of grants than those who less perceive discrimination.

However, the publishing productivity before the survey (Pt_0) has a positive relationship with research grants (Gt_1), but it is not statistically significant. Controlling the fields may reduce the direct impact of productivity on grants. Unlike in collaboration, research preference has no significant impact on grants. In terms of gender, although male scientists have slightly more grants than do female scientists, the relationship is no longer significant. The analysis also shows that the affiliation with ERCs does not make any significant difference in grant-getting activity.

In sumy, being foreign-born has no significant impact on determining the dollar amount of grants.

6.5.3 Publication productivity

Productivity before the survey period (Pt_0) is largely influenced by being foreign-born, career age, and field of research. As shown in tables 32 and 33, when other variables are controlled for, the publication productivity of foreign-born scientists over five recent years (1996 – 2000) exceeded that of native-born scientists by as much as 27% in the normal count and 17 % in the fractional count. Career age has a significantly positive effect on recent productivity (Pt_0). For each additional year of career age, the productivity increased by 1.6 % in the normal count and by 1.1 % in the fractional count. Departmental quality (Top 25) has a marginal impact on productivity (Pt_0): the scientists in the prestigious schools are more productive, by 1.1 % in the normal count and by 6.3 % in the fractional count.

Field of research also has a significant effect on productivity. The physical sciences and biology-life sciences are more productive than their reference groups, by between 20 and 30 % in the normal and fractional counts. However, computer sciences and engineering have a negative effect on productivity before the survey period (Pt_o)

In the meantime, as shown in Figure 6 and table 32 and 33, the productivity of the post survey period (2001-2003; Pt_2) is determined by collaboration, grants, previous productivity (Pt_0), foreign-born, department quality, research preference, and research field. Collaboration, grants, and previous productivity (Pt_0) all have a significant positive impact on the current productivity, *ceteris paribus*. The addition of 10 collaborators increases publication productivity by about 9 % in the normal count and about 3 % in the fractional count. In terms of the normal count, it may or may not be a good return for those who seeking collaboration. The individual return generally depends on their collaborative strategy in which some scientists collaborate simply for mentoring or entertaining purpose, but some scientists collaborate for publishing papers (Bozeman and Corley, 2004). Collaboration in the model has a significant reciprocal impact on publishing productivity.

Grants have a significant impact on the productivity (Pt_2) but its practical effect of this magnitude is not particularly important; a 100 % change in grants only makes a less than 2 % change in publication productivity, *ceteris paribus*. This may reflect the invariant effect of grants on productivity in the very large grants (Godin, 2003).

Cumulative advantage may account for publication productivity. Other things being equal, as the previous productivity (Pt_0) increases by 1 %, the later productivity (Pt_2) increases by .44 % in the normal count and by .32 % in the fractional count.

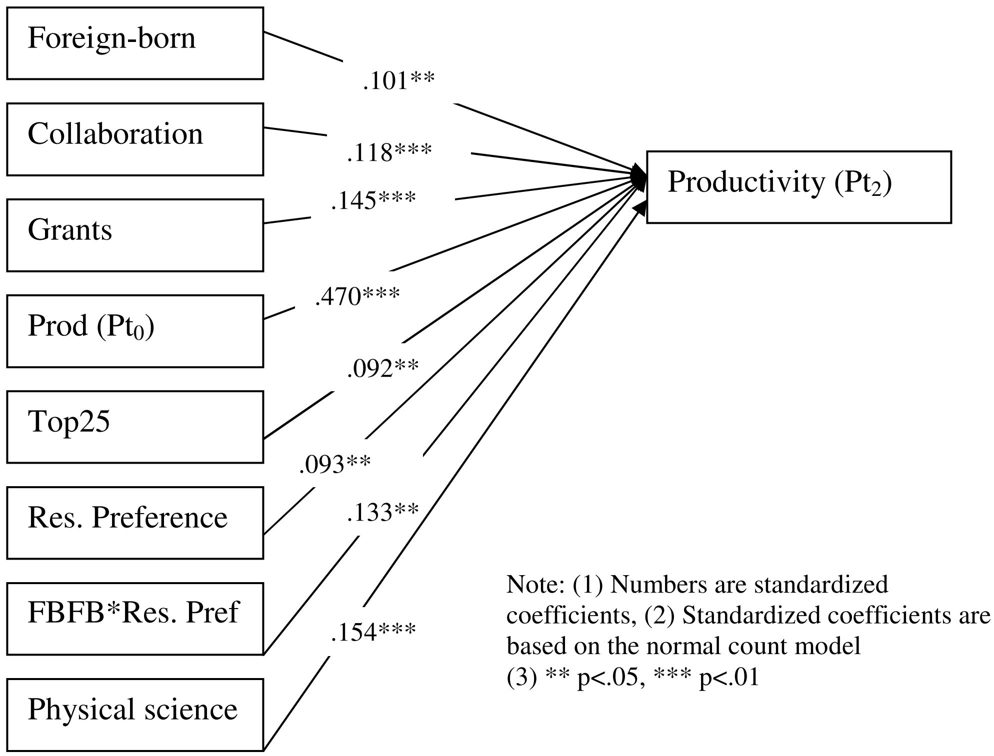


Figure 6. Determinants of productivity (Pt_2)

When other variables in the model are controlled, scientists who are foreign-born and also have foreign bachelor's degrees are more productive than native-born scientists on average by about 15 % in the normal count and by about 5.8 % in the fractional count. This implies that being a foreign-born scientist has an independent impact on publication productivity. Although this study does not go further in articulating what specific factors set foreign-born scientists apart, the fact of being foreign-born itself needs to be considered as a determining variable.

The scientists in the prestigious departments are more productive by about 13 % in the normal count and 6.5 % in the fractional count than are their counterparts in non-top 25 schools. Likewise, research motivation has a strong effect on publication productivity.

However, neither career age, gender, perceived discrimination, job satisfaction, nor a spouse's job has any significant impact on productivity (Pt_2). In particular, non-academic job experiences (mostly in industry or government) do not have a significant effect on productivity. Such a lack of difference of an effect between nonacademic job experiences and academic job-only might be explained by Dietz' Diversity Hypothesis, in which he found that the inter-and intrasectoral job changes throughout a career might result in higher research productivity (Dietz, 2004).

Fields have also different impacts on productivity. Physical sciences have a strong positive effect on productivity in both measures of publications, whereas computer sciences-mathematics and biology-life sciences have marginally negative impacts on productivity.

One of the most important questions that come up from this analysis may be how foreign-born scientists are more productive than native-born scientists are. The question could be answered, to some extent, by using interaction terms that show that a variable has a different impact for one group than for the other. This study tested 15 interaction terms that were created by multiplying being foreign-born (FBFB) variable by each independent variable. Only the interaction term of FBFB*research preference was significant at the .05 level. The current tables 33 and 34 include only the FBF*research preference. The result indicates that the relatively higher productivity of foreign-born scientists than native-born scientists could be explained, to some extent, by their stronger research preference.

Both the normal count (Table 32) and the fractional count (Table 33) show very similar coefficients in many variables. A difference is found only in the level of productivity, since normal count productivity (on average, 1.23 in recent publication productivity and 1.16 in current publication productivity) is almost twice as large as fractional count productivity (on average, .713 in recent publication productivity and .577 in current publication productivity). But the level of the mean difference does not make any significance difference in the overall result.

Considering that a non-recursive model often has relatively weak fit indices or conflicting values among the indices (Kline, 1998), the two models in this section have moderate fit indices[32]. The normal count model has Chi-square (67.33), df (17), GFI (.98), NFI (.97), and RMSEA (.047). Similarly, the fractional count model has Ch-square (60.65), df (17), GFI (.98), NFI (.98), and RMSEA (.076). Although GFI and NFI show a good fit, the Chi-square ratios (Chi-square / df =67.33/17) in both the normal and fraction models are larger than 3, which means that the fit of this overidentified model is significantly worse that if it were just-identified (Kline, 1998). In terms of the R^2 values, about 40 % of the total variation of the most recent productivity (Pt_2) is explained by the group of independent variables.[33]

To summarize, this section has examined the impact of being foreign-born on collaboration, grants, and productivity. While being foreign-born has a very marginal

[32] Kline (1998) proposes a rule of thumb to test the model fit in SEM. First, goodness-of-fit index (GFI) and net fit index (NFI) should be larger than .90. Second, Chi-square divided by degree of freedom should be smaller than three. Third, root mean square error of approximation (RMSEA) should be smaller than .10.

[33] Since the definition of R^2 is problematic for nonrecursive models, they are reported only as a general indicator of the strength of the associations and should not be interpreted in the conventional manner.

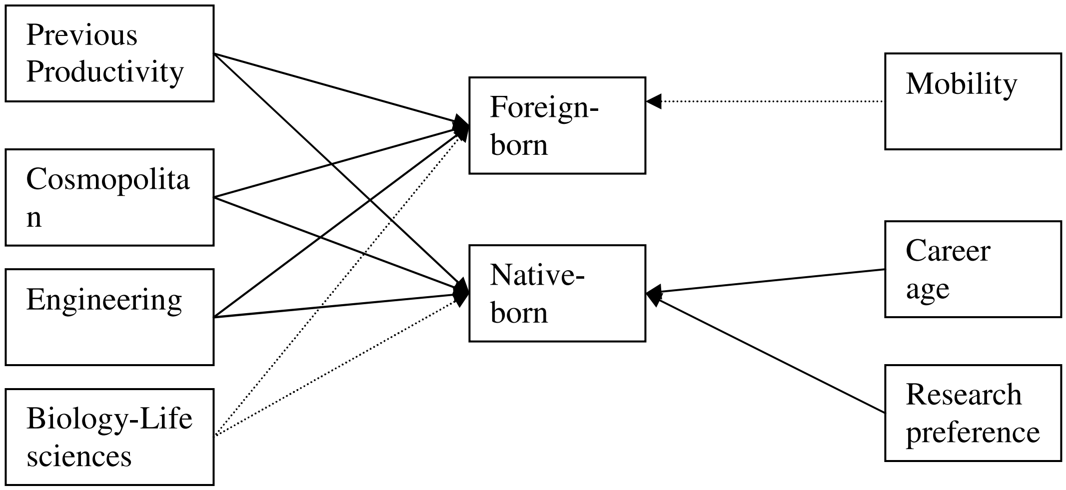
impact on collaboration and grants, it has a consistently strong impact on productivity in the presence of the relevant variables.

6.6 Differences in the determinant structures

For identifying what variable(s) differentially affect foreign-born scientists' research activity and performance, this section compares the strength and significance of the coefficients in the two subgroup models, foreign-born and native-born (Table 34 and 35).

6.6.1 Collaboration

Previous productivity (Pt_0), cosmopolitanism, and research field (engineering and biology-life sciences) significantly affect the collaboration of both foreign-born and native-born scientists (Figure 7, and Table 34 and Table 35 for the detailed information). Earlier productivity is a strong predictor for the later collaboration in both foreign-born and native-born scientists. It may be true that those who productive scientists have more S&T human capital, leading others to seek them out for collaboration. Likewise, cosmopolitanism has a significant impact on the two groups. In terms of research field, engineering and biology-life sciences have significant impact on collaboration. The former has a positive impact but the latter has a negative one. Foreign-born scientists in biology and life-sciences, compared to their native-born colleagues, are less likely to be productive than foreign-born scientist in other fields.



* Note: Solid lines are positive relationship; dotted lines are negative relationship.

Figure 7. Differences in collaboration

However, job mobility has no significant impact on the collaboration of native-born scientists, but it has a significant negative impact on that of foreign-born scientists. This poses an interesting question, why does mobility have a different impact on foreign-born than it does on native-born scientists? Although the data do not provide any reasonable clue, the cause may be that foreign-born scientists require more assimilation time than native-born scientists when they move from institution to institution. Therefore, the frequent changes might affect their ability to expand collaborative networks in a new organization.

Foreign-born and native-born scientists experience an opposite effect from career age. It has a significant positive impact on native-born scientists, but a weak negative impact on foreign-born scientists. This may indicate that increases, or decreases in some cases, in collaboration have no correspondence with the career age of foreign-born scientists. Recalling the studies of Choi (1995) and Manrique & Manrique (1999), this may reflect another aspect of immigrant scientists, which is that immigrant scientists may not be actively engaged in mentoring students and junior faculty members. In a similar fashion, the co-authorship pool has a positive impact on native-born scientists, but a negative impact on foreign-born scientists [Section 6.1.5].

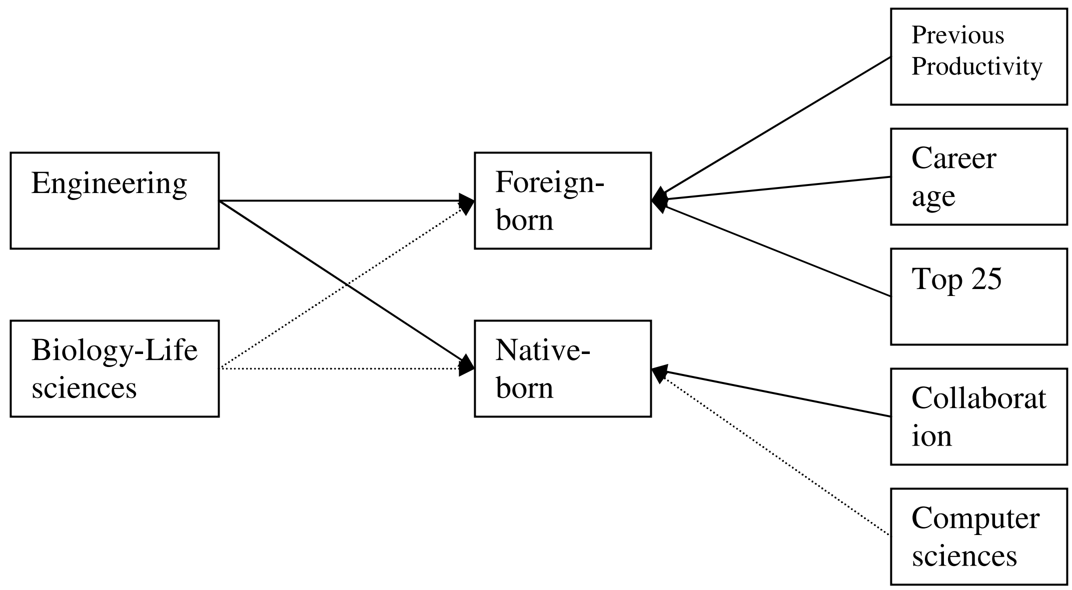
Interestingly, research preference has a significant impact on the collaboration of native-born scientists, not on that of foreign-born scientists.

6.6.2 Grants

Differences between foreign-born and native-born scientists are more obvious in grants. As shown in Figure 8 (the detailed information in tables 34 and 35), only engineering and biology-life sciences commonly affect the collaboration of both foreign-born and native-born scientists. Engineering researchers are more likely to engage in a larger dollar amount of grants than those who in other disciplines. However, biology-life sciences show a negative effect on the dollar amount of grants.

Collaboration has a large impact on the grants of native-born scientists. But it is marginally significant only at the level of .10 in both the normal and the fractional count model. Computer sciences and mathematics have a significantly negative impact on the grants of native-born scientists, not on that of foreign-born scientists.

Previous publication productivity also has different impacts; a large one on foreign-born scientists but not on native-born scientists. Controlling for other variables, a one percent increase in previous productivity yields increases of 1.10 % (in the normal count model) and 1.12 % (in the fractional count model) for grants of foreign-born scientists.



* Note: Solid lines are positive relationship; dotted lines are negative relationship.

Figure 8. Differences in grants

Career age also have a significant impact on grants for foreign-born scientists, but much less so for native-born scientists. Senior scientists among the foreign-born scientists tend to be engaged in a larger dollar amount of grants than those who are junior. This is in contrast to native-born scientists for whom career age does not make a significant difference.

Likewise, departmental quality (Top 25) has a significant effect on foreign-born scientists' grants. Foreign-born scientists in top schools are engaged in a larger dollar amount of grants than foreign-born scientists elsewhere. But such a relationship cannot be tenable for native-born scientists.

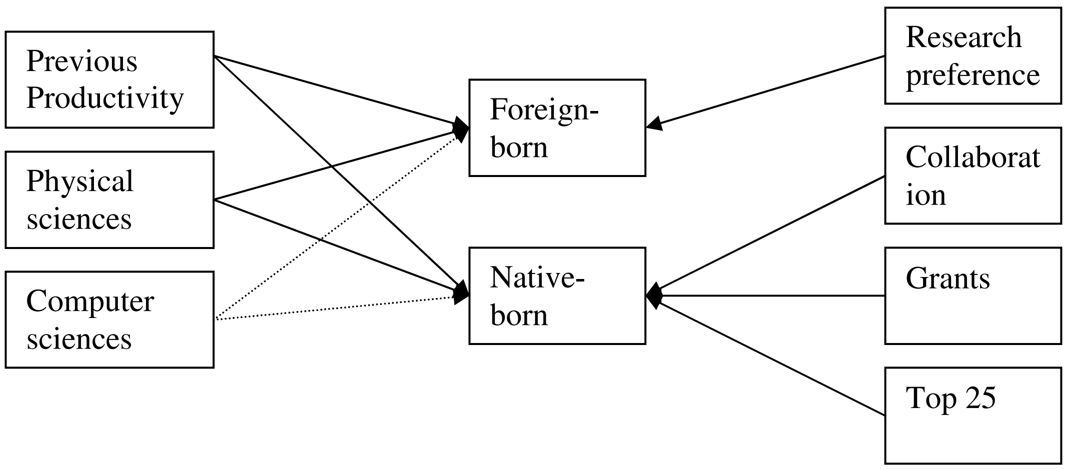
6.6.3 Publication Productivity

Publication productivity before the survey (Pt_0) is similarly determined in both native-born and foreign-born scientists. Only career age has a significant impact on the productivity (Pt_0), when gender, departmental quality, and research field are controlled. In terms of research fields, engineering has a negative impact on the productivity (Pt_0) in the native-born scientists, but not for the foreign-born scientists.

Compared to productivity (Pt_0), post-survey productivity (Pt_2) shows more differences between foreign-born and native-born scientists. As shown in Figure 9, collaboration has a significantly positive impact on productivity for native-born scientists, but no impact on foreign-born scientists. This is surprising, because the literature of science studies has regarded collaboration as having a uniform impact on productivity (Pao, 1982; Pravdic et al, 1986; Melin, 2000; Landry et al, 1996). Such no impact of collaboration on the productivity of foreign-born scientists needs more careful analysis beyond this data, because the data in this study show very close similarities between foreign-born and native-born scientists in the number of collaborators, collaboration motives, collaborative work time, and cosmopolitan scale.

Similarly, grants have more impact on productivity for native-born scientists than for foreign-born scientists. It is marginally significant for foreign-born scientists. Departmental quality has a significant impact on productivity (Pt_2) for native-born scientists, but not for foreign-born scientists. Among native-born scientists, those in the top 25 are about 16 % more productive in the normal count and about 7.6 % more in the fractional count than those who are in lesser ranked institutions.

Even among the foreign-born scientists who tend to be more research-motivated than native-born scientists, research preference has significant impact on current productivity. But this is marginally significant for native-born scientists only at the .10 α level.



* Note: Solid lines are positive relationship; dotted lines are negative relationship.

Figure 9. Differences in publication productivity

However, previous productivity (Pt_0), physical sciences and computer sciences and mathematics commonly have a significant impact on later productivity (Pt_2) in the two groups. In the normal count, a 1 % increase in prior productivity increases by .41 % of the later productivity of native-born scientists and the later productivity of foreign-born scientists by .54 %. In terms of research field, physical sciences and computer sciences have significant impacts on productivity in both models. However, career age, gender, discrimination, job satisfaction, spouse's job, nonacademic job experiences have no significant coefficients in either group.

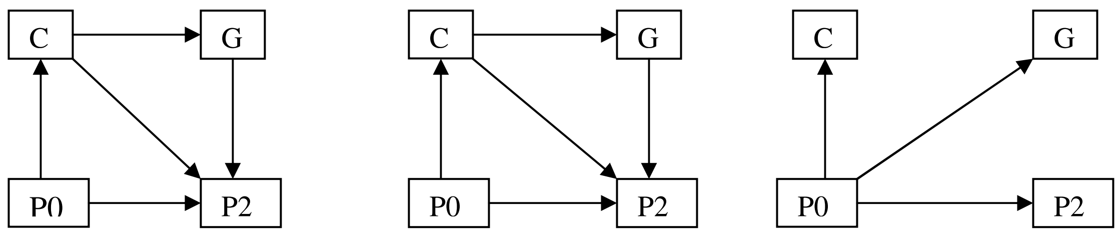
As in the whole models, the subgroup models in this section also have marginal fit indices: Chi-squares (between 37 and 51), df(18), GFI (.99), NFI (.98), and RMSEA (between .01 and .07). The R^2 values are slightly less than in the previous whole models, maybe because foreign-born variable is excluded in these subgroup models.

To summarize, the productivity of native-born scientists is more likely to be determined by collaboration, grants, prior productivity, and departmental rank, whereas that of foreign-born scientists is determined mainly by prior productivity and research preference. Collaboration and grants do not have any important impact on foreign-born scientists' productivity.

6.6.4 Reciprocal relationship among collaboration, grants, and productivity

Dealing with the framework (Section 4.2), this study built a reciprocal relationship among collaboration, grants, and productivity. Are the reciprocal relationship maintained in this analysis? As shown in Figure 10, the relationship is partially maintained. First, in the whole model and the native-born model, collaboration affects grants but not vice versa. Collaboration also affects later productivity. However, grants have an impact only on later productivity, not any other endogenous variables. Previous productivity determines both the level of collaboration and later productivity, not the dollar amount of grants. Thus, the reciprocal relationship is sustained only between collaboration and productivity as long as the high correlation between previous productivity and later productivity exists.

Second, especially in foreign-born scientists, the reciprocal relationship among collaboration, grants, and productivity seems untenable. Only previous productivity affects the level of collaboration, grants, and later productivity. Neither collaboration nor grants have significance in predicting later productivity. There is no significant relationship between collaboration and grants, either.



(a) Whole model (b) Native-born (c)Foreign-born

* Note: C is collaboration; G is grants; P0 is previous productivity (96-2000); P2 is later productivity (2001-2003)

Figure 10. Reciprocal relationship in the models

6.7 Summary of the findings

- **Mean differences in collaboration, grants, and productivity**

In terms of the number of collaborators, the difference between foreign-born and native-born scientists is not statistically significant; their mean number of collaborators is 14.04 for native-born scientists and 13.78 for foreign-born scientists. But native-born have a higher ratio of female collaborators than do foreign-born scientists. In the number of collaborators, there is a field difference; scientists in the engineering field have more collaborators than their colleagues in biology and life sciences. But within the same field, foreign-born scientists do not differ significantly from native-born scientists.

Foreign-born scientists have some differences in collaboration motivations; they are less motivated toward mentoring and socializing reasons that native-born scientist are. Foreign-born scientists are more likely to be isolated in research activity than are their native-born counterparts. They spend 22 % of their research time working alone, while native-born scientists work alone only 14 % of the time. Native-born scientists collaborate with researchers across a broader geographical distance and outside their immediate institutions. Their career total of coauthors also is higher than that of foreign-born scientists.

Differences are also found among foreign-born scientists. Although the total number of collaborators does not vary much, those who came from most advantageous countries (FBFB2) show a pattern very similar to native-born scientists. They are more motivated to mentor, more involved in collaborative work, and collaborate more with people beyond their organizations than those foreign-born scientists from less advantageous countries.

In the grant amount, grant source, and batting average, the differences between native-born and foreign-born scientists are generally marginal. They have an average of $450,000 for their current grants. But in terms of research field, engineering and computer sciences have more research grants than other fields such as biology and life sciences. Particularly, foreign-born scientists take longer time (5.6 years) to obtain their first grants after their doctoral degree than do native-born scientists (4.8 years). There is no difference in the grant proposal acceptance rate (batting average) between foreign-born and native-born scientists.

Foreign-born scientists are more productive in career average publication and recent publication than are native scientists. In both normal and fractional count, foreign-born scientists are consistently more productive. Among the foreign-born scientists, those who came from the most advantageous countries (FBFB2) are more productive than those who came from elsewhere.

- **Impact of "being foreign-born"**

Being a foreign-born scientist does not make any significant difference in collaboration and grants, when other variables are taken into account. Likewise, foreign-born scientists have slightly fewer grants than native-born scientists, *ceteris paribus*, but the relationship is significant only in the level of .10. Collaboration is determined largely by prior productivity, research preference, cosmopolitanism, and fields, whereas grants are determined by collaboration, career age, departmental rank, and field.

However, in both previous publication productivity (1996-2000) and in later publication productivity (2001-2003), being a foreign-born scientist makes a significant difference when other variables are controlled. Foreign-born scientists are more productive than are native-born scientists in both normal and fractional count measures. Along with being foreign-born, collaboration, grants, prior productivity, departmental quality, and research preference have a significant impact on current productivity. In particular, research preference has a strong positive effect on the productivity of foreign-born scientists than on that of native-born scientists.

- **Structural differences of the determinants**

Previous productivity, cosmopolitan scale, engineering, and biology-life science are strongly associated with the collaboration of foreign-born and native-born scientists. However, job mobility has a negative effect on the collaboration of foreign-born scientists, while career age and research preference have a positive effect on the collaboration of native-born scientists.

In the meantime, grants are commonly determined by engineering and biology-life sciences. However, previous productivity, career age, and departmental quality have significant impacts on the grants of foreign-born scientists, whereas only collaboration and computer sciences and mathematics have significant impacts on that of native-born scientists.

In publication productivity, collaboration and grants do not contribute to the publication productivity of foreign-born scientists, whereas the variables have major impact on the publication productivity of native-born scientists. The reciprocal relationship among collaboration, grants, and productivity persists only for native-born scientists but not for foreign-born scientists. In determining publication productivity, job satisfaction, discrimination, spouse's job, and nonacademic job experiences have no statistical significance.

CHAPTER 7

DISCUSSION AND THEORETICAL IMPLICATIONS

This study set out to examine the difference between foreign-born and native-born scientists in research activity and performance, and to further inquire to what extent they are different and why. Based on the findings presented in the previous chapter, this chapter evaluates the hypotheses (Section 7.1), and discusses implications for the theoretical background (Section 7.2) and limitations of this study (Section 7.3). Finally, some recommendations for further research are also presented (Section 7.3).

7.1 Hypotheses tests

Hypothesis 1 was that foreign-born scientists engage in fewer collaboration than do native-born scientists. In terms of number of collaborators, no significant differences are found between native-born and foreign-born scientists. In other words, this hypothesis is not supported. But other measures such as collaboration motivations, collaborative research time, cosmopolitanism, and number of co-authorship pool indicate that foreign-born scientists engage less in these activities.

Hypothesis 2 was that foreign-born scientists who came from countries where English is a major spoken language and Western culture is dominant engage in more collaboration than other foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant. As with Hypothesis 1, the number of collaborators is not significantly different among the foreign-born scientists. However, the three groups (FBFB2, FBFB1, and FBFB0) of foreign-born scientists have some differences in other measures of collaborative activity. Those who came from the most advantageous countries (FBFB2) are more committed to mentoring (helping graduate students and junior faculty members), have more collaborative research (time), higher score on a cosmopolitan scale, and more co-authors than those who came from less advantaged countries (FBFB1 and FBFB0).

Hypothesis 3 was that foreign-born scientists have fewer research grants and a lower acceptance rate of proposals than do native-born scientists. No significant difference was found in the number of grants, dollar amount of career total, career average, first, and current grants. In fact, however, in some categories, foreign-born scientists had a few more grants and engaged in larger dollar amount of grants than did native-born scientists. The batting average (the ratio of awarded proposals to submitted proposals) was not different between foreign-born and native-born scientists. Although native-born scientists submitted more proposals and were awarded more grants because of their little longer career, the career average was not different between foreign-born and native-born scientists. Thus, the evidence opposes this hypothesis.

Hypothesis 4 was that foreign-born scientists who came from the countries where English is a major spoken language and Western culture is dominant tend to have more grants and a higher acceptance rate of proposals than foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant. This hypothesis also was not supported because there is no significant difference in all the grant categories. Although it is not statistically significant, those foreign-born scientists from the least advantaged countries (FBFB0) were engaged in a larger dollar amount of grants and a higher acceptance rate of grant proposals than the rest of two groups (FBFB1 and FBFB2).

Hypothesis 5 was that foreign-born scientists are more productive than native-born scientists. In both normal and fractional count of career average publication productivity, recent publication productivity (1996-2000), and most recent publication productivity (2001-2003), foreign-born scientists are consistently more productive than native-born scientists. This hypothesis is also supported by testing the independent effect of being foreign-born scientists. After controlling all of the relevant variables, being foreign-born still exerted a significant direct effect on publication productivity.

Hypothesis 6 was that foreign-born scientists who came from the countries where English is a major spoken language and Western culture is dominant are more productive than other foreign-born scientists who came from the countries where English is not a major spoken language and Western culture is not dominant. This hypothesis is partially supported because more FBFB2 than FBFB1 are consistently productive in all the publication categories. But FBFB2 are not significantly more productive than FBFB0. Instead, FBFB0 are more productive than FBFB1.

Although this study did not specify any hypothesis for the differences in the determinants of collaboration, grants, and productivity between foreign-born and native-born scientists, the analysis showed a significant difference in the determinant structure. Career age, research preference, job mobility, departmental quality, and field (computer sciences and mathematics) have different impacts on foreign-born scientists from on native-born scientists. Along with the independent effect of being foreign-born, the differences of determinants indicate assuming that all scientists are homogeneous in research activity and performance of scientists may be untenable in the presence of foreign-born scientists.

7.2 Implications for the theoretical background

The major finding of this study is that there is no significant difference in research collaboration and grants between foreign-born and native-born scientists, although foreign-born scientists are more productive. At the inception of this study, it was assumed that foreign-born scientists are less engaged in collaboration and have fewer grants, but are more productive. With consideration of the discrepancies and conformances, this section discusses implications for the theoretical background on which this study is based.

7.2.1 Language and cultural reasons

Two of the most apparent barriers that foreign-born scientists face in their work environment might be language and culture. Greater language proficiency and cultural assimilation are expected to make them collaborate more easily and participate more in collaborative research activity. However, the findings do not show that language and culture are major factors in research activity, at least in focusing on the number of collaborators and grant amount. Although this study does not have a direct measure of current language proficiency and cultural assimilation, the three groups that reflect the national origin based on linguistic and cultural similarity do not show a significant difference in research collaboration and grants.

The primary reason seems to lie with the sample in which most of the foreign-born scientists obtained their doctoral degree in the United States and stayed, on average, for 17 years in the United States. This fact substantially reduces variation in culture and language, and makes any difference that might distinguish foreign-born scientists less visible in research activity.

Another important reason could also be ascribed to the selection effect. Working in the U.S. preconditions (e.g., job interviews) the foreign-born scientists to have proper language skills and cultural understanding. Therefore, language and cultural factors might not have much influence on research activity and performance. Rather, the different behavioral pattern and style that foreign-born scientists bring to their research activity might have more impact on the potential difference in research. For example, foreign-born scientists work alone significantly more than do native-born scientists. This difference could be explained not just by language and cultural factors but also by inherent behavior patterns that are intrinsic to the cultures of the foreign-born scientists and unrelated to their discipline.

Although language and cultural reasons occupy a weak position in this analysis, an interpretation of their impact on research activity should carefully consider their embedded nature.

7.2.2 Particularistic characteristics

The simplest explanation of particularism in differences between foreign-born and native-born scientists would be that foreign-born scientists are different from native-born scientists due to "being a foreign-born scientist." It does not specify any detailed reason since the particularistic characteristic is not easily comparable in most cases. A more complex form of the particularism explanation is to identify as many particularistic characteristics as possible and then to reduce unexplained variations as much as possible.

The analysis shows that collaboration and grants are determined more by prior productivity, departmental quality, cosmopolitanism, or previous coauthorship, but less by the isolated condition of being a foreign-born. Foreign-born scientists' perception of discrimination does not have any effect on research collaboration and grants, whereas publication productivity as a typical nonparticularistic characteristic has a significant positive effect on both collaboration and grants. Likewise, foreign-born scientists' job satisfaction and family relations (spouse's job) do not make any difference on research activity and performance. These points are consistent with what Melin (2000) calls "pragmatic reasons," for scientists to engage in research activity, and unrelated to "functionally irrelevant characteristics."

In sum, the particularism explanation is weak in this case because being foreign-born does not make significant difference in research activity and because scientists are more likely to rely on other factors such as pragmatic reasons, regardless of their national origin or race.

7.2.3 Sacred sparks of foreign-born scientists

In this analysis, one factor that consistently makes a difference in research activity and performance between foreign-born and native-born scientists is research preference. The stronger motivation of foreign-born scientists is associated with the higher level of research performance such as collaboration and publishing productivity.

The explanation resonates with the sacred spark theory in which Cole and Cole (1976) argue that a scientist's innate ability and motivation are important factors in determining her research performance. Setting aside the innate ability that is notoriously difficult to measure, foreign-born scientists have reasons to have strong research preferences. First, the major reason for foreign-born scientists to stay in the United States is to do research (Choi, 19975, p45-52; Song, 1993). Foreign-born scientists usually believe that the United States is the best place for research and they want to do research that would be impossible elsewhere. Success in research is often regarded as their primary goal (Choi, 1995). Second, even if foreign-born scientists are interested in other activities or jobs (e.g., administrative positions) other than research, their chances of getting them, compared to native-born scientists, are not good (Choi, 1995). There is considerable evidence of this glass ceiling effect in which some groups – minority or immigrants – often experience limitations and barriers to being promoted to a higher managerial position (Woo, 1994; Waldinger et al, 1998; Tang, 2000). If this is indeed the case, foreign-born scientists may voluntarily or involuntarily stick to research instead of pursuing any other activity or position. Any further inquiry into why foreign-born scientists are more motivated for research is beyond the scope of this research. But it helps to show why and how foreign-born scientists differ from native-born scientists.

7.2.4 Selection and embedded effect

Selection and the embedded disadvantage effect provided an important basis for the research hypotheses of this study. While the former props up reasons why foreign-born scientists are more productive than native-born scientists, the latter explains why foreign-born scientists are engaged in fewer collaborations and have fewer grants. The findings presented in Chapter 6 show mixed results. The selection effect seems to explain foreign-born scientists' higher research productivity, whereas the embedded disadvantage effect seems lose its strength in supporting their lower levels of collaboration and grants.

This study does not have any direct measure to account for the selection effect. It is embedded in foreign-born scientists. Working in the United States means "being selected" largely because of their ability in research. Therefore, it does not make much sense to draw a direct conclusion that the selection effect contributes to the higher productivity of foreign-born scientists. But it can be speculated that the unvaryingly higher productivity of foreign-born scientists is explained, to some extent, by the selection effect. Although the selection effect is mainly concerned with productivity, it also works to explain the similarity between foreign-born and native-born scientists in collaboration and grants. As a foreign-born scientist is hired in a U.S. institution, selection includes not only the scientist's research per se but also his or her research-related abilities such as language skills.

Compared to the selection effect, the embedded disadvantage effect seems weak. In the analysis of collaboration and grants, no significant difference exists among the group of foreign-born scientists based on the language and cultural category. Although foreign-born scientists perceive discrimination more than do native-born scientists, it does not significantly affect collaboration and grants. As explained in section 7.2.1 and 7.2.2, research activity, regardless of whether it is foreign-born or native-born, is more likely to be determined by pragmatism and merit reasons than by particularistic characteristics such as language, culture, or any other reason that is stems simply from "being foreign-born."

7.2.5 Assimilation and cohort effect

Among foreign-born scientists, how long they have stayed in the United States could be an important indicator of their difference in research activity and performance, because longer experience in the United States makes them better trained and grounded in research and more assimilated in language and culture. The assimilation effect is often confounded with career age, particularly in the case of scientists. Most of the foreign-born scientists in this study obtained their doctoral degree in the United States and have stayed since then. Career age (years after doctoral degree), therefore, constitute good proxies for assimilation and cohort in the analysis.

The findings imply that the assimilation effect has no strong impact on research collaboration and productivity, but has some impact on grants. In terms of collaboration, younger scientists, who generally have been in the United States for a shorter time than their seniors, surprisingly have more collaborators than do their senior counterparts who have stayed longer. There is no significant difference between them in productivity. But senior foreign scientists have more grants, on average, when other variables in the model are controlled for..

However, this study does not provide a separate cohort analysis comparing only the same cohort of native-born and foreign-born scientists. This requires a larger sample that can provide enough cases for each cohort.

7.3 Limitations of this study and suggestions for future study

This study has limitations that should be recognized. In addition, some suggestions are made for future research.

7.3.1 Sample

The sample of this study has some limitations. First, it was collected from only the scientists in the NSF and DOE research centers. Although it has some benefits (e.g., the primary work is research) in comparing research activity and performance, the sample is not representative of the whole group of scientists in the United States, even in academia. A broader sampling is needed that represents the total population of academic scientists in the United States.. In particular, the concentration of this sample in research centers makes variation in research grants less apparent because most scientists in research centers have grants. In this case, neither the amount of grants nor the probability of grant-getting (including the number of grants) has a significant effect on collaboration and productivity.

Second, and closely related to the first concern, at a minimum, the sample size for foreign-born scientists should be increased, making the testing of its hypotheses more robust. The subgroups of foreign-born scientists are too small in this study (e.g., FBFB2 is 25). Realistically, this makes the ANOVA results unreliable.

Third, the sample used in this study covers several disciplines. Considering the different nature of disciplines, this limits the causal inferences available from the analysis. A study in which the sample were in the same discipline would yield results with a much more powerful explanation of cause and effect. Although this study uses four dummy variables for fields of work, these are insufficient to control for the various differences between disciplines. For example, biologists tend to secure funds from NIH rather than other agencies. Similarly there are substantially different patterns of publication among fields.

7.3.2 Validity of measures

The measurements used in this study have some important validity issues. First, this study focuses only on the number of journal articles as the measure of research productivity; the quality of research and other outputs (e.g., patent, conference proceedings) are excluded. All of the journal articles were counted equally without weighting the quality of journals and the impact or quality of articles. Also, the productivity measure excluded patents and conference proceedings. Patents are a major research output, particularly in some engineering fields (e.g., mechanical engineering and bio-engineering). Conference proceedings (with peer review) are equally important in some disciplines (.e.g., computer science and computer engineering). Therefore, the publication productivity should be interpreted cautiously.

Second, grant amount has some weaknesses in measuring grant activity. Since grant amount substantially depends on the nature of research, a scientist's activity for obtaining grants is not well reflected in the grant amount that the scientist secures. If a research involves in a big science project or corresponds with urgent national needs, the grant amount often is bigger than ones that are not as "big" or as timely. For coping with this problem, some studies use the probability of getting grants as the measure of grant activity (Liebert, 1977; Onida and Malerba, 1989). However, the problem seems not be solved very well, particularly in this study because most scientists in engineering and science department at Doctoral Research Universities (Extensive) [34] have some types of research grants. The grant probability is not enough to be variant for a useful analysis.

Third, some concerns are with measuring the constructs such as research preference, job satisfaction, and discrimination. Although there is a reasonable level of internal reliability (Cronbach Alpha) among items and considerable face validity in each item, the measurement of the constructs still needs to be based on more solid theoretical support, which is, in fact, rare in this case.

7.3.3 Data limitation

The survey data lacks some important variables that could significantly improve the causal inference. It does not have data to measure the level of language proficiency, cultural assimilation, and reasons for staying in the United States. Although this study categorizes the difference by the two distance indices (Miller index and Hofstede index) based on national origin, the category cannot fully deal with the difference between native-born and foreign-born scientists. It could be a good measure for the difference among the foreign-born scientists, not a direct measure for that between foreign-born and native-born scientists. In addition, the information about reasons and motivations to stay in the United States could help understand why foreign-born scientists are more research-oriented.

In the meantime, the data for this study is not fully available for a longitudinal analysis of the reciprocal relationship among collaboration, grants, and productivity. It is

[34] According to the Carnegie Classification, Doctoral Research Universities (Extensive) is largely consistent with the traditional definition of Research I University.

important to see a longitudinal causal path among them because there is a sizable possibility that there are some time lags in cause and effect among them.

7.3.4 Generalizability

Some cautions are also needed in generalizing the findings for the whole population of scientists in the United States. As mentioned in section 5.1 and 7.3.1, the sample is limited to scientists who are affiliated with NSF or DOE research centers. In a sense, they could be, compared with the scientists in the less research-focused institutions (e.g., Non-Research Universities or Non-Doctoral/Research Universities-Extensive), a special group of scientists who are more likely to work for research interests, have more grants and resources, and to whom research is the major criterion for their career achievement. Since research activity and performance may have different value depending on institutional characteristics, the findings of the study are a better fit for scientists in research universities.

7.3.5 Suggestions for future study

Any future study should properly address the limitations mentioned in the preceding section. Moreover, there are more opportunities for improving the study. A first step would be using a large data source to identify foreign-born scientists, for example, the use of NSF's Survey of Earned Doctorates (SED) and the Survey of Doctorate Recipients (SDR), is recommended for the sampling strategy. SDR and SED have information on citizenship, national origin, educational background, career plans, and demographic data. NSF conducts SED for every new doctoral recipient in the United

States. The response rate for SED is more than 92 percent.[35] SDR, on the other hand, is a longitudinal panel survey of individuals who have received their doctorates in the sciences or in engineering. SDR is overseen by the NSF and its 2001 survey was conducted by the U.S. Census Bureau.[36] It has rich information on work, employment, wages, job experiences, and professional activity. SDR has a sample size of around 40,000[37].

Although the SDR does not include those who obtained their doctoral degrees abroad, such a large coverage of SED and SDR[38] would reduce the risk of sampling error. Particularly, age and graduation cohort comparisons would be of great advantage. The drawback of the SED data is that it is only useful for guiding sampling and not for investigating research activity and performance. The SED and SDR data do not have any measure of collaboration and include partial or limited information on grants. But the SDR has profession activity data such as the number of conference presentations, publications generated, and patents applied for. SED provides only information on demography, institution, graduate life/program, and career plan at the time when graduate students obtain doctoral degrees in the United States. Therefore, the data do not include scientists who obtained their doctoral degrees in foreign countries. Nonetheless, the coverage and rich information of SDR and SED would be a good source for further investigation and a possible ingredient in the sampling strategy.

---

[35] The response rate of 2001 Survey of SDR was 82.6 percent (NSF's SDR Methodology: http://www.nsf.gov/sbe/srs/ssdr/sdrmeth.htm)

[36] The U.S. Census Bureau conducted the 2001 survey. Until 1995, the survey was conducted by the National Research Council of the National Academy of Sciences under contract to SRS; the 1997 survey was conducted by the National Opinion Research Center (Chicago, IL) (http://www.nsf.gov/sbe/srs/ssdr/sdrmeth.htm).

[37] The sample size of 1999 and 2001 SDR is 40,000.

[38] However, it should be identified whether an independent researcher could sample from the SDR because there may be some legal constraints in using the confidential data.

Second, a qualitative approach also is recommended in providing detail descriptions of foreign-born scientists' research activity and performance. In-depth interviewing might be very useful for examining the selection effect, research motivation, and collaborative interaction that cause the differences between foreign-born and native-born scientists.

Third, it might be meaningful to conduct intensive research about scientists of the same national origin. It would be possible to elucidate who is coming to and staying in the United States by comparing scientists of the same nationality. The approach would help us understand how they are selected and what factors affect their selection. A more important reason to recommend such an intensive case study of the same national origin is that it could provide detailed information on language/cultural and particularistic characteristics issues that are commonly shared among people of the same national origin.

CHAPTER 8

CONCLUSION AND POLICY IMPLICATIONS

This chapter summarizes the main findings (Section 8.1), identifies the contributions to the literature (Section 8.2), and then discusses the policy implications of this study (Section 8.3).

8.1 Summary of the main findings

- Foreign-born scientists have a similar number of collaborators, a similar strategic motivation for collaboration, and a similar number of coauthorship pool as their native-born scientists. However, foreign-born scientists tend to work alone for a higher proportion of their research time than their native-born counterparts. Also, foreign-born scientists than native-born scientists are less likely to be cosmopolitan in terms of the geographical proximity of collaboration. Among foreign-born scientists, there is no significant difference in the number of collaborators, but FBFB2 (foreign-born scientists from the most advantageous countries in terms of language and cultural difference) are more likely to be motivated toward mentor-oriented collaboration and to spend a higher proportion of research time for collaborative research than are FBFB1 (foreign-born scientist from the less advantageous countries) and FBFB0 (foreign-born scientists from the least advantageous countries). In terms of cosmopolitan scale and coauthorship pool, no significant difference is found among foreign-born scientists.

- In multiple indicators for research grants such as career average amount of grants, number of grants, career first grants, current grants, grant sources, grant batting average, time lag for career first grants, significant differences are not found between foreign-born and native-born scientists. Likewise, there is no significant difference among foreign-born scientists.

- Unlike collaboration and grants, there is a consistent difference in publishing productivity between foreign-born and native-born scientists. Foreign-born scientists are more productive than native-born scientists in both measures (normal and fractional count) of publications and in three different time periods. Even in controlling for the discipline, foreign-born scientists are generally more productive than native-born scientists. Among foreign-born scientists, FBFB2 and FBFB0 are slightly more productive than FBFB1, the difference is not significant.

- In terms of research environment, foreign-born scientists than native-born scientists perceive more discrimination based race and nationality. FBFB0 perceive more discrimination than FBFB1 and FBFB2. The scientists in the sample, regardless national origin, are generally satisfied with their jobs; there is no significant difference in the composite score. However, foreign-born scientists are more motivated for their research than their native-born counterparts are.

- Being foreign-born has a significant impact on publishing productivity, controlling for other factors such as grants, collaboration, career age, gender, departmental rank, research motivation, discrimination, job satisfaction, spouse job, non-academic job experience, and fields. This indicates that being foreign-born may play an important role in research, based on their particular characteristics.

- Although there are some common determinants for collaboration, grants, and productivity in both foreign-born and native-born scientists, there are substantial differences. First, job mobility has a negative impact on foreign-born scientists' collaboration but no impact on native-born scientists.' Second, departmental quality has a strong positive impact on foreign-born scientists' grants but no impact on native-born scientists'. Third, collaboration has a strong positive impact on the grants (dollar amount) of native-born scientists but a marginal one on that of foreign-born scientists. Likewise, collaboration, grants, and departmental quality have a strong positive impact on the productivity of native-born scientists but a very weak one on that of foreign-born scientists.

8.2 Contributions to the literature

This study significantly contributes to the current literature of S&T policy and immigration policy. First of all, this study provides a rare empirical result to the policy research community, by improving the understanding of the differences between foreign-born and native-born scientists, and by shaping the theoretical foundations. In contrast to the general perception, foreign-born scientists are not different significantly from native-born scientists in collaboration and grants. Particularistic characteristics that foreign-born scientists bring with them do not make any substantial difference in research activity. Language and cultural effects are not significant as much as in other studies that look generally at immigrants and not specifically at scientists. Since the doctoral scientists are trained and educated more than the general population, the effect of language and culture is relatively small. In a similar way, while discrimination is often a major barrier for immigrants in their work environment, it appears to be no longer an important barrier in collaboration and grants of foreign-born scientists. This finding seems to favor the universalistic interpretation of research more than a particularistic interpretation. In terms of productivity, however, foreign-born scientists are more productive, largely due to their strong research preference and motivation. The results provide important implications for selection effect and also for further research on the motivational differences.

Second, the methodological challenge of this study is worth noting. A large data of CVs and surveys were collected and coded. Unlike a single survey study, this study combined CV data and survey data, providing more detailed information and making it possible to test such a complex model. Especially the RVM team made a tremendous effort in coding the CVs. As previous studies (Dietz et al, 2000; Dietz, 2004) revealed, CVs are very useful in studying scientists' career pattern, job experience, publication, and professional affiliations. In the meantime, the survey was structured for measuring collaboration, grants, research environment, and motivation. Based on such detail dataset, this study tested reciprocity among collaboration, grants, and productivity, which is rare in the current literature. The framework that this study built would provide important guides for future study. Although the variables that this study included do not cover all the characteristics of foreign-born scientists, the different impact of the variables on foreign-born scientists than on native-born scientists and the significant effect of being foreign-born indicate that a new study should consider the heterogeneity among scientists through which the status of being foreign-born might contribute to research productivity.

In addition, this study developed several indicators that are rarely available in other studies. Collaboration is measured by the number of real collaborators, not the simple number of coauthors. A cosmopolitan scale is used in examining scientists' quasi-geographical collaboration pattern. As one of the unique approaches that this study adopts, the number of coauthors was counted throughout the career publications of scientists without duplication to see if there is a difference in the coauthorship pool. Job mobility was tracked from the CVs to identify differences of foreign-born scientists. Another noteworthy contribution that this study makes is to use both a normal and a fractional count of publication at the same time. Fractional count data is not easily available in similar productivity studies because it requires a tedious coding process.

8.3 Policy implications

Although this study deals mainly with faculty members in the academic institutions, it has profound implications for the overall immigration and science policy relevant to foreign-born students and scientists because most foreign-born scientists who work in the academic institutions initially came as a graduate student.

First of all, this study has direct implications for the debate of *open vs. close door* in the immigration of highly skilled labor. The findings may promote the optimistic view of maintaining at least the current level of openness for foreign scientists. This study shows that foreign-born scientists are more productive than their native-born scientists, with a similar level of engagement in collaboration and grants. This is contrary to what proponents of a *closed door* policy would expect from foreign-born scientists' research activity and performance. Although immigration policy is often considered through economic and political lenses, the higher productivity and active participation in research activity of foreign-born scientists among other important factors may considerably augment the benefit side in the cost-benefit paradigm surrounding immigration policy.

However, the optimistic view seems not much reflected in the reality that foreign-born scientists endure in their entry to and their living in the United States. The admissions of foreign graduate students this fall compared with the fall of 2003 dropped by 18 percent, according to NAFSA survey of 480 institutions (Bollag, 2004b). There are many causes for the decline of America's international prominence. Sept. 11 seems to be a central factor. The increased concern about security, the Patriot Act, and other restrictions have created a profound change in attitudes and perceptions, both within the US and abroad. Many tales of the difficulties that students and scholars from abroad have in obtaining visas, the perceived disrespect for visa applicants shown at American embassies around the world, and the delays inherent in the entire immigration system have been significant deterrents (Altbach, 2004). It is often reported in the international education community that professors who work with foreign students and scientists have delayed research projects and staffing problems because the entry of their foreign collaborators was often unexpectedly delayed, and that foreign scholars working at American institutions sometimes stuck outside the United States for long periods when they travel to attend an academic conference (Zhao, 2004). Considering the stringent situation, foreign-born scientists who have a temporary visa are often recommended not to travel outside the United States by their institutions (Wilson, 2004).

From a long-term perspective, a more serious concern may be the worldwide perception that the United States is a less welcoming place than it was before (Bollag, 2004a). The perception may diminish the attractiveness of the United States as the first choice for foreign students seeking a higher quality education. It is obvious that foreign scientists are necessary for keeping the current level of research in many research organizations in the United States. For example, almost 68% of engineering postdocs are foreign-born; most of them have a temporary visa (COSEPP, 2000). They are an important source of innovative research and U.S. competitiveness. If such unfriendly situation continues, foreign scientists might prefer other advanced countries for continuing their research. For example, Australia, Canada, and Britain have been vigorously recruiting international students and these countries have recorded a substantial increase of foreign students' enrollment over last three years (Bollag, 2004a). As frequently resonated in the brain gain or drain issue, the shrinkage of foreign enrollment and the loss of attractiveness may bring in a negative effect on U.S. science in the long-term perspective.

Second, this study also has implications for the research environment and resources of foreign-born scientists. Although the major quantitative indicators of this study showed that foreign-born scientists do not differ in collaboration and grants from their native-born scientists, more qualitative observations in this study and in other cases still raise various issues in foreign-born scientists' research activity. According to *The Scientist* magazine survey (Park, 2001), a majority of foreign-born scientists responded that the biggest problem in research is communication because of the language difference. The respondents recommended an institutional supporting program for the new immigrant scientists. For example, they wanted an intensive language course or mentoring program for learning English. As reported in a recent *Science* article (Mervis, 2004), even foreign-born scientists who graduated from the U.S. universities still have language problems in their early career stage as a faculty member. Some foreign faculty members said that no student wanted to take them as thesis committee members and relatively few students took their classes. Despite the poor job in communication and mentoring activity in the early career, they usually achieve excellent research records in their later career. Such a dramatic change should not be treated as a simple matter of assimilation but it should draw some more attention to their career pattern in research activity and performance. Foreign scientists may be slow starters primarily because of their less adaptation to the embedded disadvantages in the early career but they make themselves more productive and more engaged in collaboration in the later career. The data of this study shows that compared to native-born scientists, foreign-born scientists are less engaged in collaboration and have fewer grants and are slightly less productive especially during the first three years after Ph.D. Although the difference is not statistically significant, it indicates that there is a more rapid change in the level of research activity and performance after the time threshold. Such a seemingly different life cycle is not appropriately reflected in the visa policy. The H-1b visa grants three years to the new immigrant scientists and can be extended to the maximum of five years (six years on special cases) by the employer's decision. The three-year limitation may be not long enough for foreign scientists to show their ability and be assimilated to their organizational environment. In particular, newly minted foreign doctoral scientists (F1 visa holders) should leave this country in two months from their graduation date, unless they find a job in the United States. These regulations substantially limit the staying conditions of new foreign doctoral scientists and in turn the United States might lose the new talents before it could see their contributions to U.S. science. If this is the general case, it seems reasonable that the regulated time limit should be appropriately extended at least for the newly minted foreign doctoral scientists so that they can practice their new knowledge in the United States for an appropriate time period.

In terms of grant-getting activity, this study found that foreign-born scientists have a bigger time lag in obtaining their career first research grant as a PI after receiving their Ph.D. than do their native-born counterparts. Although this is not seen as a result of discrimination in the current grant system, it implies that a grant program might be needed for foreign-born scientists in the early career. As *The Scientists* magazine survey also identified, foreign postdocs in the research institutions strongly agree with that grant opportunities should be increased for new comers who have great research potentials.

Third, this study contains important implications for the role of university research centers, especially regarding this question, "how different impact does the center affiliation have on foreign-born scientists than on native-born scientists?" It may be true that scientists' affiliation with research centers makes them to be easily engaged in more collaboration and to have increased opportunity of research grants because the research centers are oriented toward more interdisciplinary research and multi-purpose research (Bozeman and Boardman, 2003). Compared to foreign-born scientists who are not affiliated with research centers, center affiliated foreign-born scientists may have even more advantages in their research activity and performance, given the embedded disadvantages. Such a different impact of center affiliation on foreign-born scientists than on native-born scientists may be a mere speculation, because any direct comparison between center-affiliated researchers and not-affiliated researchers was not made in this study. However, this study found that, very differently from the literature-guided assumption, foreign-born scientists do not differ in collaboration and grants from native-born scientists. The indifference between foreign-born and native-born scientist could be interpreted in several ways but the most important factor among other reasons seems to be the center affiliation. Among the scientists who are affiliated with a center, the number of collaborators may not be very different because the important collaboration is often made in their immediate group. Center-affiliated scientists also collaborate for seeking their research grants as a team. Beyond the finding, this issue seems to deserve more study to provide an important guide to the policy makers.

Fourth, this study has implications for S&T human capital, which is defined as the sum of scientists' scientific and technical knowledge, work relevant skills and social ties and resources (Bozeman et al., 2001). S&T human capital is the unique set of resources the individual brings to his or her own work and to collaborative efforts. As the findings presented, native-born scientists are more likely to be motivated toward mentoring junior scientists in their collaboration, and also they have a higher percentage of female collaborators than do foreign-born scientists. In terms of research time portfolio, foreign-born scientists are more likely to work alone, compared with their native-born colleagues. The cosmopolitan scale difference also indicates that native-born scientists are engaged in more inter-organizational collaboration than are their foreign-born scientists. Although the number of collaborators is similar between native-born and foreign-born scientists, such differences in mentor-motivation, female ratio, collaborative research time, and cosmopolitan scale appear to have a critical implication to the formation of S&T human capital.

Finally, the overall impressions and observations through this study suggest that the government may need to develop a more specified policy for foreign-born doctoral scientists, particularly for new comers or young career scientists, by combining some features of the immigration and science policy. Immigration policy (e.g., visa policy) is dominated by potential and existing economic consequences, focusing more on *foreign* than *scientists* in the two-words of foreign scientists. By contrary, science policy (e.g., evaluation programs and grants programs) is not sophisticated enough to cope with the particular aspects of foreign-born scientists in the United States. For example, very few grant programs address the issues of young career foreign scientists. It seems the most important missing link that neither immigration nor science policy properly covers foreign-born doctoral researchers in academia. The current immigration policy is too vague for doctoral scientists. H1b visa policy, a major device to deal with "highly skilled labors," does not have any explicit policy for doctoral researchers, broadly including scientists of bachelor's and master's degrees. The entry quota for doctoral scientists may need to be set independently from the whole population of scientist category because doctoral scientists are usually working in more research-intensive environment. On the other hand, science policy is rarely engaged in the particularistic features of foreign-born scientists. The importance of foreign-born scientists especially in the academic institutions seems not well connected to and reflected in the immigration policy such as visa and quota system.

Although this study produces valuable results about how differently foreign-born scientists are engaged in research and how 'being foreign-born' makes differences in research, more extensive research including lesser ranked institutions (e.g., Doctoral Research Universities-Intensive or Mater's Colleges and Universities) should be supported to provide in-depth information to the policy community.

APPENDIX A.

TABLES

Table 5. Chiswick & Miller Index and Hofstede Index

Category	Chiswick & Miller Index (Language)	Geert Hofstede Index (Culture)	Composite (Language + Culture)	Term
Group 1 Chiswick & Miller Index (less than 1.6) Hofstede Composite Difference (more than 121)	Korea Japan Iran Taiwan China Egypt	Brazil Pakistan Taiwan Turkery Japan Korea China Colombia Thailand Mexico Singapore Venezuela Chile	China Egypt Iran Japan Korea Mexico Taiwan Turkey Venezuela	**FBFB0** (Least Advantageous= Neither western culture nor English-spoken)
Group 2 Chiswick & Miller Index (1.6-2.4) Hofstede Composite Difference (61-120)	India Greece Turkey Hungary Yugoslavia Thailand Slovenia Romania Poland Czechoslovakia Switzerland Spain Germany Denmark Argentina Venezuela Mexico Ukraine Russia	Italy Netherlands Finland Norway India Belgium Argentina Iran Sweden Austria France Denmark Israel Hong Kong Philippines Spain	Belgium Czech Denmark France Germany Greece India Italy Netherlands Poland Portugal Romania Russia Slovenia Spain Switzerland	**FBFB1** (Less advantageous= Either western culture or English-spoken)
Group 3 Chiswick & Miller Index (more than 2.4) Hofstede Composite Difference (0-60)	Italy Belgium France Portugal Netherlands UK Canada Australia Ireland	Australia UK Canada New Zealand Switzerland Ireland Germany	Australia Canada Ireland New Zealand UK	**FBFB2** (Most advantageous= Western culture + English-spoken))

Table 5 (continued)
Note: (1) Hofstede Index
Hofstede created ordinal scales for countries for each of the four dimensions based on a standardized factor analysis of questionnaires administered between 1968 and 1972 to 88,000 national employees in more than 40 overseas subsidiaries of a major American corporate. It is now most often used as an index of cultural difference among nations (Brouthers and Brouthers, 2001).
Power Distance Index (PDI) focuses on the degree of equality, or inequality, between people in the country's society. A High Power Distance ranking indicates that inequalities of power and wealth have been allowed to grow within the society. These societies are more likely to follow a caste system that does not allow significant upward mobility of its citizens. A Low Power Distance ranking indicates the society de-emphasizes the differences between citizen's power and wealth. In these societies equality and opportunity for everyone is stressed.
Individualism (IDV) focuses on the degree the society reinforces individual or collective, achievement and interpersonal relationships. A High Individualism ranking indicates that individuality and individual rights are paramount within the society. Individuals in these societies may tend to form a larger number of looser relationships. A Low Individualism ranking typifies societies of a more collectivist nature with close ties between individuals. These cultures reinforce extended families and collectives where everyone takes responsibility for fellow members of their group.
Masculinity (MAS) focuses on the degree the society reinforces, or does not reinforce, the traditional masculine work role model of male achievement, control, and power. A High Masculinity ranking indicates the country experiences a high degree of gender differentiation. In these cultures, males dominate a significant portion of the society and power structure, with females being controlled by male domination. A Low Masculinity ranking indicates the country has a low level of differentiation and discrimination between genders. In these cultures, females are treated equally to males in all aspects of the society.
Uncertainty Avoidance Index (UAI) focuses on the level of tolerance for uncertainty and ambiguity within the society - i.e. unstructured situations. A High Uncertainty Avoidance ranking indicates the country has a low tolerance for uncertainty and ambiguity. This creates a rule-oriented society that institutes laws, rules, regulations, and controls in order to reduce the amount of uncertainty. A Low Uncertainty Avoidance ranking indicates the country has less concern about ambiguity and uncertainty and has more tolerance for a variety of opinions. This is reflected in a society that is less rule-oriented, more readily accepts change, and takes more and greater risks.

(2) Chiswick & Miller Index
This is a measure of the difficulty of learning a foreign language for English-speaking Americans. It is based on a set of language scores measuring achievements in speaking proficiency in foreign languages by English-speaking Americans at the U.S. Department of State, School of Language Studies. It is assumed, greater linguistic distance between English and the specific foreign language. For example, French is scored at 2.5 (in a range from 1 to 3) while Japanese is scored at 1.0 (Chiswick and Miller, 1998, p. 195).

Table 6. National origin of the foreign-born scientists

Country	Category	Frequency	Percent	Cum Percent
Australia*	Oceania	4	2.88	2.88
Belgium	Europe	2	1.44	4.32
Canada*	N. America	5	3.60	7.92
Cyprus	Europe	1	0.72	8.64
Czech Republic	Europe	3	2.16	10.79
Denmark	Europe	2	1.44	12.23
France	Europe	4	2.88	15.11
Germany	Europe	10	7.19	22.30
Greece	Europe	4	2.88	25.18
Hungary	Europe	1	0.72	25.90
Ireland	Europe	1	0.72	26.62
Italy	Europe	5	3.60	30.22
Latvia	Europe	1	0.72	30.94
Netherlands	Europe	2	1.44	32.38
Poland	Europe	1	0.72	33.10
Portugal	Europe	1	0.72	33.82
Romania	Europe	2	1.44	35.25
Russia	Europe	3	2.16	37.41
Slovenia	Europe	1	0.72	38.13
Spain	Europe	1	0.72	38.85
Switzerland	Europe	5	3.60	42.45
Turkey	Europe	3	2.16	44.61
UK	Europe	14	10.07	54.68
Ukraine	Europe	1	0.72	55.40
Yugoslavia	Europe	2	1.44	56.83
Subtotal (* are included)	**Europe**	**79**	**56.84**	
China	Asia	15	10.79	67.63
Egypt	Asia	3	2.16	69.78
Hong Kong	Asia	1	0.72	70.50
India	Asia	17	12.23	82.73
Iran	Asia	4	2.88	85.61
Japan	Asia	3	2.16	87.77
South Korea	Asia	2	1.44	89.21
Taiwan	Asia	4	2.88	92.09
Thailand	Asia	1	0.72	92.81
Subtotal	**Asia**	**50**	**35.97**	
Antigua & Barbuda	Others	1	0.72	93.53
Argentina	Others	1	0.72	94.24
Cuba	Others	3	2.16	96.40
Mexico	Others	1	0.72	97.12
Tunisia + Canada	Others	1	0.72	97.84
Venezuela	Others	1	0.72	98.56
Subtotal	**Others**	**8**	**5.76**	
Unknown	Unknown	2	1.44	100.00
Total		**139**	**100.00**	

Table 7. Places of degree obtained

Obtained Degree	Undergraduate Degree			Doctoral Degree		
	All	Foreign-born	Native-born	All	Foreign-born	Native-born
US universities	319 (73.2)	23 (16.9)	296 (98.7)	379 (90.5)	93 (71.5)	286 (98.9)
Foreign Universities	117 (26.8)	113 (83.1)	4 (1.3)	40 (9.5)	37 (28.5)	3 (1.1)
Total	436 (100)	136 (100)	300 (100)	419 (100)	130 (100)	289 (100)

* Note: Parentheses are percentages in each column

Table 8. Disciplinary distributions

Origin	Count	Engineerin g	Physics Chemistry	Biology Life sciences	Math Computer	Missing	Total
Native -born	Count	128	72	79	16	9	304
	% within FBvsUB	42.1%	23.7%	26.0%	5.3%	3.0%	100.0%
	% within discipline	68.8%	64.9%	81.4%	47.1%	75.0%	69.1%
	% of Total	29.1%	16.4%	18.0%	3.6%	2.0%	69.1%
Foreig n-born	Count	58	39	18	18	3	136
	% within FBvsUB	42.6%	28.7%	13.2%	13.2%	2.2%	100.0%
	% within discipline	31.2%	35.1%	18.6%	52.9%	25.0%	30.9%
	% of Total	13.2%	8.9%	4.1%	4.1%	.7%	30.9%
Total	Count	186	111	97	34	12	440
	% within FBvsUB	42.3%	25.2%	22.0%	7.7%	2.7%	100.0%
	% within discipline	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	42.3%	25.2%	22.0%	7.7%	2.7%	100.0%

Table 9. Rank of foreign-born and native-born Scientists

Rank	Foreign-born		Native-born		Total	
	Frequency	%	Frequency	%	Frequency	%
Assistant Professor	38	27.9	79	25.7	117	26.4
Associate Professor	27	19.9	48	15.6	75	16.9
Full Professor	44	32.4	125	40.7	169	38.1
Valid Total	109	80.1	252	82.1	361	81.5
Unknown	27	19.9	55	17.9	82	18.5
Total	136	100.0	307	100.0	443	100.0

Table 10. Measurements

Variables	Measurement
Collaboration	Number of collaborator (2000-2001: one year) Collaboration motivation: 13 motivation items (4 Likert scale) Collaborative research time portpolio: percentage Co-authorship pool: number of co-authors
Grant	Grant amount (2000-2001): Natural log (current grants + 1) – "1" is added for solving zero grants Career average of grants: total amount of career grants/ number of years after doctoral degree Career first grants and time lag: Dollar and number of years after doctoral degree Grants sources: Nominal Grants proposals and awards (Batting average) = (#awards)/(#proposals)
Productivity(P_{t0})	NC and FC of peer-reviewed journal articles between 1996 and 2000, Natural log Career average productivity (total publications divided by the number of years
Productivity(P_{t2})	NC and FC of peer-reviewed journal articles between 2001 and 2003, Natural log
Foreign-born (1=FB)	1= foreign-born and foreign bachelor, 0 = US-born and bachelor (Others were excluded for the analyses)
Career age	Years after doctoral degree
Gender (male=1)	1= male, 0=female
Top25	An indicator for current departmental quality. It is based on National Research Council data ("Research-Doctorate Programs in the United States Continuity and Change, 1995"). The ranking scores are a composite of educational quality, faculty reputation and activity, funding measures, program size measures, program composition measures. Relying on the total scores, 1= top 25, 0= otherwise.
Research preference	Composite score based on two items ("my scientific work is the most important thing in my life" and "there is nothing as satisfying as doing the best science possible"). The inter-item reliability (Alpha) is .6371.
Discrimination	1-4 Liker scale (4-strongly agree, 1-strongly disagree) about discrimination due to national origin and race.
Cosmopolitan scale	0-5 (0: least cosmopolitan, 5: most cosmopolitan)
Mobility	Career average number of job experiences (different institutions)
Co-authorship pool	Career average number of co-authors
Research center	1= ERCs, 0= others
Job satisfaction	Composite score based on three items ("I am satisfied with my job" and "my colleagues in this department appreciate my research contributions" and "I think I am paid about what I am worth in the academic market." The inter-item reliability (Alpha) is .548.
Spouse job	1= Spouse is a fulltime homemaker, 0= otherwise
Non-academic job	1= non-academic job experience, 0 = otherwise
Field	Four dummies: Engineer (all engineering fields), physical (physics and chemistry), biolife (biology and medicine), and comput (math and computer)

Table 11. Number of collaborators

Category	Native-born (a) N= 293	FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	ANOVA F	ANOVA Sig
		FBFB					
Total number of collaborators	14.04	13.78	11.36	12.08	17.11	1.022	0.383
Total male collaborators	10.28	10.63	8.61	9.36	13.11	1.022	0.383
Total female collaborators	3.76	3.14	2.95	2.71	4.00	1.804	0.146
Total faculty collaborators	5.90	5.40	4.65	4.76	6.42	0.459	0.711
Total grad student collaborators	5.83	6.27	5.30	5.54	7.77	1.135	0.335
Male faculty	4.63	4.34	3.78	3.79	5.20	0.440	0.725
Female faculty	1.27	1.02	0.87	0.92	1.23	1.067	0.363
Male grad students	3.88	4.71	3.87	4.19	5.63	2.074	0.103
Female grad students	1.95	1.55	1.43	1.34	2.14	2.014	0.112
Male not university researcher	1.80	1.55	0.96	1.36	2.28	1.894	0.130
Female not university researcher	0.54	0.56	1.43	1.34	2.14	0.246	0.865
% grad student collaborators	0.41	0.43	0.39	0.42	0.45	0.804	0.492
% faculty collaborators	0.42	0.40	0.45	0.41	0.37	0.198	0.898
% collaborators in ones' own work group	0.82	0.83	0.84	0.83	0.82	0.076	0.973
% female collaborators	0.28[b,e]	0.23[a]	0.27	0.23	0.23[a]	3.396	0.018

* Note: (1) FBFB (Foreign-born and Foreign-bachelors), FBFB2 (FBFB from the advantageous countries), FBFB1 (FBFB from the less advantageous countries), FBFB0 (FBFB from the least advantageous countries). (2) Upper scripts indicate a significant difference in the level of .05. For example, the upper script "a" in the column FBFB2 (c) means that FBFB2 has a significant difference with the column (a).

Table 12. Total number of collaborators by field

Field	Total (N=406)	Native-born (N=293)	Foreign-born (N=113)	T-test Sig.
Engineering	15.38	15.50	15.14	.814
Physical sciences	13.67	14.28	12.56	.420
Bio-life sciences	11.07	11.25	10.30	.567
Computer/math	14.13	13.96	14.28	.834

* Note: ANOVA test for the differences among the disciplines (F=4.91, p=.002)

Table 13. Collaboration motivations

Motivations	Native-born (a) N=293	Foreign-born FBFB (b) N=113	FB2 (c) N=21	FB1 (d) N=57	FB0 (e) N=35	ANOVA F	Sig
Time known person	2.77	2.66	2.70	2.52	2.85	2.213	.086
Admin request	2.08	2.19	2.05	2.05	2.50	2.244	.083
Help Jr. colleague	$2.90^{b,d}$	2.71^{a}	3.20^{d}	$2.57^{a,c}$	2.65	4.117	.007
Strong sci. reputation	3.24	3.32	3.15	3.30	3.44	.973	. 405
Complementary skills	3.78	3.80	3.70	3.89	3.71	1.576	.195
Quality other collaborator	3.76	3.68	3.52	3.68	3.77	1.487	.218
Help grad students	3.18	3.06	3.00	3.07	3.08	.745	.526
Fun or entertaining	$2.94^{b,e}$	2.72^{a}	2.75	2.83	2.53^{a}	3.088	.027
Fluent my language	$2.53^{b,c,d}$	2.05^{a}	1.80^{a}	2.05^{a}	2.20	10.965	.000
Same nationality	$1.86^{b,c,d,e}$	1.53^{a}	1.45^{a}	1.59^{a}	1.47^{a}	11.113	.000
Strong work ethic	$3.49^{b,c}$	3.34^{a}	3.10^{a}	3.37	3.43	2.977	.031
Sticks to schedule	3.23	3.14	3.05	3.07	3.31	2.006	.113
How assign credit	2.69	2.61	2.60	2.52	2.77	1.060	.366

* Note: (1) FBFB (Foreign-born and Foreign-bachelors), FBFB2 (FBFB from the advantageous countries), FBFB1 (FBFB from the less advantageous countries), FBFB0 (FBFB from the least advantageous countries). (2) Upper scripts indicate a significant difference in the level of .05. For example, the upper script "a" in the column FBFB2 (c) means that FBFB2 has a significant difference with the column (a).

Table 14. Research time

Research Time	Native-born (a) N= 293	Foreign-born FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	ANOVA F	Sig
Working alone	14.16[b,d]	21.55[a]	14.33	25.63[a]	21.26	6.507	0.000
Working with researchers and graduate students in my immediate work group	52.01	48.91	53.50	45.21	49.68	1.548	0.202
Working with researchers in my university, but outside my immediate work group	12.74	10.94	14.44	10.50	10.82	0.865	0.459
Working with researchers in U.S. universities other than my own	9.85[b,d,e]	7.39[a]	10.31[d,e]	6.75[a,c]	5.91[a,c]	2.186	0.035
Working with researchers in U.S. industry	6.01	5.83	5.27	5.57	5.58	0.153	0.928
Working with researchers in U.S. government laboratories	3.35	3.31	1.44	4.25	3.50	0.726	0.537
Working with researchers who reside in nations other than U.S.	5.60	5.95	5.52	6.74	4.81	0.446	0.721

* Note: (1) FBFB (Foreign-born and Foreign-bachelors), FBFB2 (FBFB from the advantageous countries), FBFB1 (FBFB from the less advantageous countries), FBFB0 (FBFB from the least advantageous countries). (2) Upper scripts indicate a significant difference in the level of .05. For example, the upper script "a" in the column FBFB2 (c) means that FBFB2 has a significant difference with the column (a).

Table 15. Cosmopolitan scale

Cosmopolitan scale	Native-born (a) N= 293	Foreign-born FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	ANOVA F	Sig
Cosmopolitan scale	2.50[b]	2.36[a]	2.50	2.35	2.32	1.914	0.127

Table 16. Cosmopolitan scale by field

Field	Total (N=406)	Native-born (N=293)	Foreign-born (N=113)	T-test Sig.
Engineering	2.46	2.50	2.37	0.131
Physical sciences	2.52	2.60	2.38	0.078
Bio-life sciences	2.38	2.38	2.37	0.984
Computer/math	2.52	2.66	2.37	0.125

* Note: ANOVA test for the differences among the disciplines (F=1.286, p=.279)

Table 17. Co-authorship pool

Co-authorship	Native-born (a) N= 293	Foreign-born				ANOVA	
		FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	F	Sig
Career total	47.23[b]	36.59[a]	41.95	39.98	40.97	0.603	0.613
Career average	3.02	3.56	3.47	3.34	3.72	0.548	0.605

Table 18. Career average co-authorship by field

Field	Total (N=406)	Native-born (N=293)	Foreign-born (N=113)	T-test Sig.
Engineering	3.13	2.94	3.54	0.264
Physical sciences	3.99	3.96	4.05	0.920
Bio-life sciences	3.84	3.60	4.92	0.379
Computer/math	2.35	2.34	2.36	0.967

* Note: ANOVA test for the differences among the disciplines (F=4.78, p=.01)

Table 19. Grant amount

Grants	Measures	Native-born (a) N=124	Foreign-born (b) N=49	Sig
Career Grants total (g)	Mean Median	6,034,764 3,143,685	7,212,730 3,910,019	.416
Career Grants average (g/career age)	Mean	481,086	504,216	.842

*Note: T-Test results are based on the natural logarithm of the current grants due to the normality reason

Table 20. Career grants average by field

Field	Total (N=173)	Native-born (N=124)	Foreign-born (N=49)	T-test Sig.
Engineering	524,650	548,329	476,303	0.765
Physical sciences	424,547	358,052	546,455	0.305
Bio-life sciences	365,093	361,931	394,329	0.909
Computer/math	793,210	107,867	571,172	0.021

* Note: ANOVA test for the differences among the disciplines (F=5.01, p=.01)

Table 21. First and current grants

Grants	Measures	Native-born (a) N= 287	Foreign-born				ANOVA	
			FBFB (b) N=111	FBFB2 (c) N=22	FBFB1 (d) N=56	FBFB0 (e) N=33	F	Sig
First grants	Mean Median	223,075 104,968	222,851 150,000	214,681 150,000	255,098 150,000	173,575 100,000	.321	.81
Current grants	Mean Median	2,210,441 435,000	2,388,040 490,000	2,140,470 500,000	2,374,594 450,000	2,551,188 594,813	.227	.87

* Note: (1) ANOVA test results are based on the natural logarithm of the grant amount due to the normality reason. (2) N is based on the current grants

Table 22. Current grants by field

Field	Measures	Total (N=398)	Native-born (N=287)	Foreign-born (N=111)	T-test Sig.
Engineering	Mean Median	2,886,339 350,000	2,708,163 350,000	3,119,397 308,019	.592
Physical sciences	Mean Median	2,217,634 482,000	2,654,732 450000	1,276,193 594,813	.729
Bio-life sciences	Mean Median	1,715,717 730,518	1,372,120 700,000	377,300 400,000	.130
Computer/math	Mean Median	984,688 554,500	895,285 624,500	1,088,992 500,000	.394

* Note: ANOVA test for the differences among the disciplines (F=4.50, p=.04). ANOVA test is based on the natural log.

Table 23. Number of career grants and sources

Source	Measures	Native-born (N=146)	Foreign-born (N=57)	Sig.
Government	Mean Median St.Dev	9.68 7.00 8.23	10.91 7.00 11.39	.708
Industry	Mean Median St.Dev	5.24 4.00 5.25	7.54 4.00 7.20	.110
Non-profit	Mean Median St.Dev	3.64 2.00 3.44	4.16 3.00 3.48	.675
Foreign country	Mean Median St.Dev	1.00 1.00 0.00	4.44 2.00 5.00	.072
Total	Mean Median St.Dev	19.56 14.00 12.16	18.29 16.00 17.56	.304

Table 24. Current grant sources

Source	Measures	Native-born (N=271)	Foreign-born (N=112)	Total (N=383)
Industry*	Count % within grant source % within UB vs FB % of Total	55 69.6% 20.3% 14.4%	24 30.4% 21.4% 6.3%	79 100.0% 20.6% 20.6%
Government	Count % within grant source % within UB vs FB % of Total	216 71.1% 79.7% 56.4%	88 28.9% 78.6% 23.0%	304 100.0% 79.4% 79.4%
Total	Count % within grant source % within UB vs FB % of Total	271 70.8% 100.0% 70.8%	112 29.2% 100.0% 29.2%	383 100.0% 100.0% 100.0%

* Note: (1) Chi-Square Test (Pearson): Value =.062, df=1, Asymp.Sig (2-sided) =.803. (2) Industry includes the grants from private foundations.

Table 25. Grant proposals and awards

Grants	Native-born (a) N= 266	Foreign-born FBFB (b) N=112	FBFB2 (c) N=21	FBFB1 (d) N=56	FBFB0 (e) N=35	ANOVA F	Sig
Number of research proposals submitted (α)	33.64[d]	27.72	22.66	22.87[a]	38.65	2.287	.078
Number of research proposals awarded(β)	18.15[b,d]	14.62[a]	13.76[e]	11.21[a,e]	20.71[c,d]	2.452	.050
Batting average (β/α)	.56	.55	.56	.50	.61	2.070	.104

Table 26. Batting average by field

Field	Total (N=370)	Native-born (N=259)	Foreign-born (N=111)	T-test Sig.
Engineering	0.527	0.523	0.535	0.725
Physical sciences	0.589	0.584	0.598	0.771
Bio-life sciences	0.611	0.624	0.515	0.097
Computer/math	0.480	0.466	0.494	0.729

* Note: ANOVA test for the differences among the disciplines (F=4.774, p=.003).

Table 27. Time lag for first grants

Grants	Native-born (a) N= 276	Foreign-born FBFB (b) N=112	FBFB2 (c) N=21	FBFB1 (d) N=56	FBFB0 (e) N=35	ANOVA F	Sig
Years between first grants and doctoral degree	4.77 (3.00)	5.61 (4.00)	7.18 (6.00)	5.55 (4.00)	4.71 (3.50)	1.022	.383

* Note: Parentheses are the medians.

Table 28. Publication productivity

Publications	Native-born (a) N= 293	Foreign-born				ANOVA	
		FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	F	Sig
Career average (NC)	3.027[bce]	3.710[a]	4.274[ad]	3.238	4.138[ad]	2.469	.050
Recent average (1996-2000) NC	3.609[bce]	4.405[a]	5.230[ad]	3.983	4.694[a]	2.501	.050
Recent average (1996-2000) FC	1.305[b]	1.573[a]	1.757[ad]	1.472	1.648[a]	2.471	.051
Post-survey period average (2001-2003) NC	2.837[bce]	3.827[a]	3.826[a]	3.318	4.620[a]	3.853	.010
Post-survey period average (2001-2003) FC	.867[be]	1.208[a]	1.250	1.033	1.457[a]	4.968	.002

* Note: (1) NC stands for normal count; FC stands for fractional count. (2) Career average (FC) is not available.

Table 29. Publication productivity by field

Period	Field	Total (N=406)	Native-born (N=293)	Foreign-born (N=113)	T-test Sig.	ANOVA
Career average (NC)	Engineering	2.84	2.56	3.45	0.008	F=6.887 P< 0.001
	Physical sciences	4.03	3.79	4.46	0.060	
	Bio-life sciences	3.13	3.08	3.33	0.227	
	Computer/math	1.93	1.91	2.48	0.050	
Recent average (1996-2000) (NC)	Engineering	3.06	2.54	4.22	0.001	F=8.641 P<0.001
	Physical sciences	4.94	4.90	5.03	0.901	
	Bio-life sciences	3.69	3.61	4.05	0.093	
	Computer/math	1.83	1.58	2.05	0.088	
Recent average (1996-2000) (FC)	Engineering	1.17	0.97	1.62	0.002	F=5.796 P<0.001
	Physical sciences	1.66	1.66	1.67	0.965	
	Bio-life sciences	1.39	1.42	1.30	0.743	
	Computer/math	0.78	0.67	0.87	0.102	
Post survey (2001-2003) (NC)	Engineering	3.04	2.67	3.86	0.015	F=7.665 P<0.001
	Physical sciences	4.32	4.06	4.80	0.214	
	Bio-life sciences	2.55	2.37	3.33	0.064	
	Computer/math	1.68	1.25	2.07	0.098	
Post survey (2001-2003) (FC)	Engineering	1.00	0.86	1.31	0.004	F=4.932 P<0.002
	Physical sciences	1.22	1.14	1.37	0.107	
	Bio-life sciences	0.77	0.74	0.94	0.171	
	Computer/math	0.61	0.40	0.79	0.038	

Note: (1) T-test is used for testing the group difference between foreign-born and native-born scientists in each field. (2) ANOVA reports the statistical difference among the discipline.

Table 30. Differences in other variables

Factors	Native-born (a) N= 293	Foreign-born				ANOVA	
		FBFB (b) N=113	FBFB2 (c) N=21	FBFB1 (d) N=57	FBFB0 (e) N=35	F	Sig
Top 25	.49	.52	.43	.59	.46	1.05	.370
Research Preference	5.40[b]	5.94[a]	5.80	6.02[a]	5.87[a]	4.89	.002
Discrimination	1.11[b]	1.38[a]	1.13	1.34[ac]	1.57[ac]	13.21	.000
Job satisfaction	9.22	9.09	9.30	8.97	9.17	.51	.676
Job mobility	.52[b]	.81[a]	.74[ad]	.91[ac]	.68[a]	4.14	.006
Center[ERCs]	.26	.34	.34	.40	.23	2.23	.084
Non-academic job	.46	.37	.43	.35	.37	1.15	.326
Spouse job	.32[b]	.23[a]	.09[ade]	.24[ac]	.28[ac]	2.27	.050

* Note: Numbers are mean.

Table 31. Descriptive statistics of variables in the model

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Collaboration	406	.00	85.00	13.8429	9.093
Log. Grant	398	.00	18.42	10.2013	5.680
Log. Productivity(P_{t0}) NC	406	.00	3.23	1.2374	.751
Log. Productivity(P_{t0}) FC	406	.00	2.05	.7135	.483
Log. Productivity(P_{t2}) NC	406	.00	3.18	1.1609	.703
Log. Productivity(P_{t2}) FC	406	.00	2.18	.5777	.427
Foreign-born (1=FB)	409	.00	1.00	.3086	.462
Career age	409	.00	46.00	17.7411	10.895
Gender (male=1)	409	.00	1.00	.8770	.328
Top25	409	.00	1.00	.5035	.500
Research preference	409	2.00	8.00	5.5696	1.389
Discrimination	409	1.00	4.00	1.1971	.511
Cosmopolitan scale	406	.04	3.60	1.4419	.485
Mobility	403	.00	9.00	.6085	.867
Research center [ERC]	406	.00	1.00	.2905	.454
Non-academic job experiences	406	.00	1.00	.44	.497
Job satisfaction	406	4.00	12.00	9.1838	1.617
Spouse job	406	.00	1.00	.2907	.454
Engineering	406	.00	1.00	.422	.494
Physical sciences	406	.00	1.00	.252	.434
Bio-life sciences	406	.00	1.00	.220	.415
Computer sciences/Math	406	.00	1.00	.078	.269
FBFB*Research Preference	406	.00	8.00	1.833	2.848

Table 32. Maximum Likelihood Estimates (productivity: normal count)

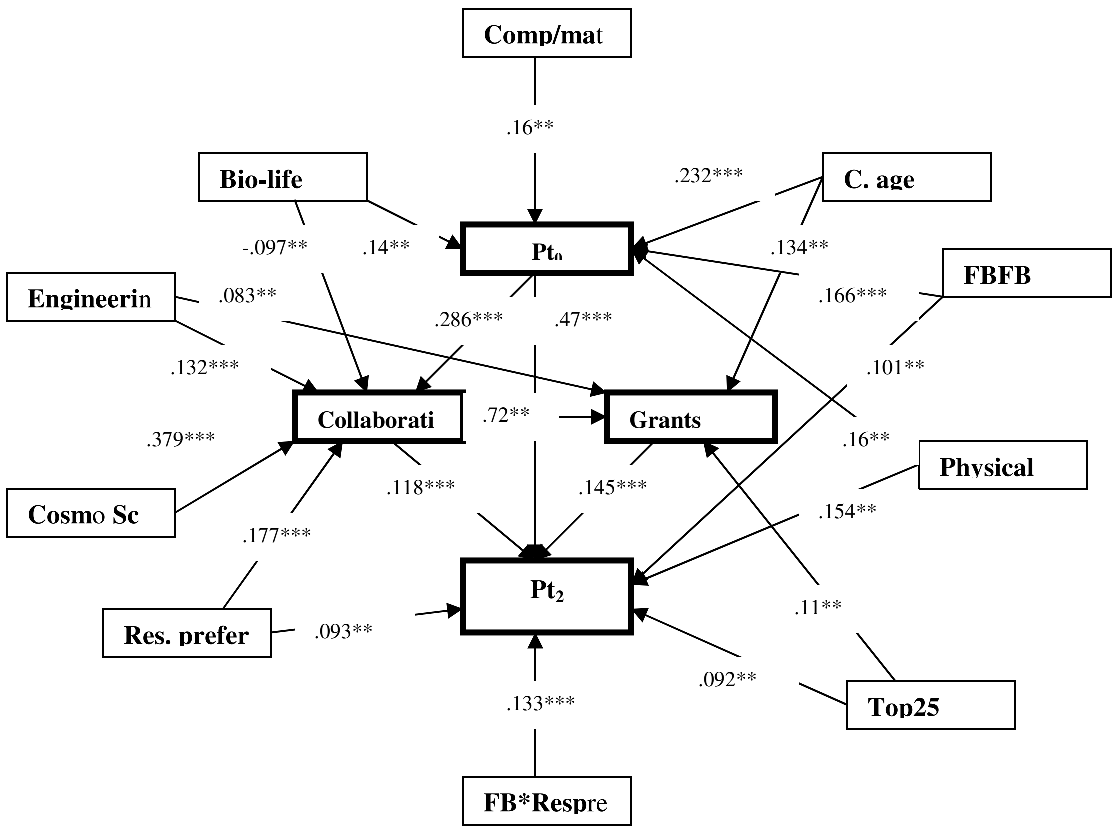
Exogenous variables	Endogenous variables Collaboration (2000-2001) C_{t1}	Grant (2000-2001) G_{t1}	Productivity (1996-2000) P_{t0}	Productivity (2001-2003) P_{t2}
Collaboration		.45*** (.13)		.0092*** (.0031)
Grant	.13 (.40)			.018*** (.005)
Productivity(P_{t0})	3.47*** (.93)	.61 (.50)		.44*** (.039)
FBFB (FBFB=1)	-1.86* (1.34)	-.99* (.75)	.27*** (.078)	.155** (.84)
Career age	.08* (.063)	.07** (.031)	.016*** (.003)	-.0028 (-.0028)
Gender (male=1)	.97 (1.66)	.77 (.097)	.058 (.11)	.043 (.085)
Top25	1.19 (1.15)	1.25** (.62)	.011* (.069)	.13*** (.054)
Research preference	1.16*** (.42)	.054 (.25)		.047*** (.021)
Discrimination	-.16 (1.08)	.99* (.64)		.036 (.056)
Cosmopolitan scale	7.12*** (1.36)			
Mobility	-.36 (.67)			
Research center [ERC]		.55 (.71)		
Job satisfaction				.025* (.018)
Spouse job				.0013 (.061)
Non-academic job exp			-.047 (.072)	-.042 (.056)
Engineering	2.44** (1.50)	.83** (.44)	-.13 (.10)	-.23* (.16)
Physical sciences	-.66 (.67)	.48 (.40)	.29** (.16)	.25** (.14)
Bio-life sciences	-2.14** (1.22)	-.51* (.39)	.26** (.13)	-.10 (.09)
Computer/math	1.06* (.79)	-.76* (.58)	-.74** (.43)	-.53* (.33)
FBFB*Research Preference				.033** (.016)
Intercept	-3.18 (7.04)	-4.85 (4.13)	-.33** (.18)	-.021 (.38)
R^2	.34	.21	.13	.41
Model Fit Index	Chi-square = 67.33 *df*=17, GFI (.98), NFI(.97), and RMSEA(.047)			

* Note: (1) * p<.10, ** p<.05, *** p<.01. (2) The parentheses are standard errors.

Table 33. Maximum Likelihood Estimates (productivity: fractional count)

Exogenous variables	Endogenous variables			
	Collaboration (2000-2001) C_{t1}	Grant (2000-2001) G_{t1}	Productivity (1996-2000) P_{t0}	Productivity (2001-2003) P_{t2}
Collaboration		.44*** (.14)		.0036** (.0018)
Grant	.14 (.39)			.012*** (.003)
Productivity(P_{t0})	4.77*** (1.39)	.88 (.75)		.44*** (.036)
FBFB (FBFB=1)	-1.73* (1.34)	-.97* (.75)	.17*** (.05)	.058** (.031)
Career age	.086* (.064)	.069** (.032)	.011*** (.002)	-.0016 (-.002)
Gender (male=1)	1.01 (1.68)	.78 (.098)	.029 (.07)	.010 (.052)
Top25	1.30 (1.16)	1.26** (.62)	.063* (.045)	.065** (.033)
Research preference	1.23*** (.43)	.057 (.26)		.040*** (.013)
Discrimination	-.21 (1.09)	.98* (.65)		.006 (.034)
Cosmopolitan scale	7.47*** (1.39)			
Mobility	-.27 (.67)			
Research center [ERC]		.54 (.72)		
Job satisfaction				.015* (.011)
Spouse job				.024 (.037)
Non-academic job exp			-.015 (.047)	-.026 (.034)
Engineering	2.31** (1.72)	.81** (.43)	-.14 (.13)	-.12 (.20)
Physical sciences	-.71 (.69)	.51 (.41)	.20** (.12)	.12** (.22)
Bio-life sciences	-2.10** (1.14)	-.49* (.35)	.31** (.22)	-.22 (.20)
Computer/math	.99 (.92)	-.79* (.56)	-.50** (.28)	-.23** (.15)
FBFB*Research Preference				.029** (.015)
Intercept	-3.95 (7.13)	-4.92 (4.14)	-.24 (.28)	-.15 (.23)
R^2	.36	.22	.12	.41
Model Fit Index	Chi-square = 63.68 *df*=17, GFI (.98), NFI(.98), and RMSEA(.076)			

* Note: (1) * p<.10, ** p<.05, *** p<.01. (2) The parentheses are standard errors.



Note: (1) Numbers are standardized coefficients, (2) The standardized coefficients are based on the normal count model. (3) ** p<.05, *** p<.01

Figure 11. Significant relationships in the whole model

Table 34. Structural differences (productivity: normal count)

Variables	Collaboration		Grants		Productivity (t_0)		Productivity (t_2)	
	Native-born	Foreign-born	Native-born	Foreign-born	Native-born	Foreign-born	Native-born	Foreign-born
Collaboration			.43*** (.13)	.49* (.37)			.011*** (.003)	.004 (.006)
Grant	.23 (.48)	.91 (.88)					.020*** (.006)	.013* (.008)
Productivity(P_{t0})	2.83*** (1.07)	5.21*** (2.05)	.35 (.55)	1.10** (.65)			.41*** (.046)	.54*** (.074)
Career age	.16** (.084)	-.096 (.10)	.055* (.037)	.12** (.07)	.014*** (.004)	.019*** (.006)	-.0049* (.003)	.002 (.005)
Gender (male=1)	.51 (1.99)	2.06 (3.66)	.14 (1.08)	3.40* (2.27)	.049 (.12)	.010 (.24)	.088 (.097)	.11 (.18)
Top25	1.68 (1.42)	-.39 (.88)	.61 (.74)	2.95*** (1.43)	.12* (.084)	.074 (.13)	.16*** (.065)	.039 (.10)
Research preference	1.08** (.53)	.95* (.68)	-.002 (.30)	.044 (.52)			.041* (.025)	.12*** (.038)
Discrimination	.11 (1.77)	-.53 (1.26)	1.24 (.97)	.82 (.97)			.046 (.083)	.028 (.084)
Cosmopolitan scale	8.46*** (1.78)	4.21** (2.08)						
Mobility	.079 (1.25)	-1.41** (.79)						
Research center [ERC]			.56 (.85)	.51 (1.39)				
Job satisfaction							.019 (.021)	.039 (.037)
Spouse job							-.036 (.072)	.082 (.12)
Non-academic job exp					-.035 (.089)	-.047 (.13)	-.024 (.068)	-.074 (.10)
Engineering	2.29** (1.26)	2.59** (1.58)	.79** (.50)	1.63** (.92)	-.12** (.07)	.10 (.07)	-.36 (.33)	.24 (.15)
Physical sciences	-.58 (.51)	-.71 (.66)	.40 (.35)	.90 (.26)	.34*** (.20)	.24* (.21)	.28** (.17)	.17** (.10)
Bio-life sciences	-2.04** (1.20)	-3.81** (1.76)	-.47** (.27)	-1.26** (.97)	.23** (.14)	.04 (.25)	-.12* (.33)	-.06 (.11)
Computer/math	.97 (.80)	1.23* (.88)	-.76** (.46)	-.81* (.53)	-.81** (.45)	-2.22** (1.21)	-.84** (.35)	-88** (.40)
Intercept	-5.13 (8.02)	7.66 (5.56)	-3.38 (4.24)	-5.98 (5.42)	-.33 (.44)	.75*** (.28)	.14 (.40)	-.73* (-.47)
R^2	.37	.17	.24	.10	.13	.12	.38	.26
Model Fit Index	US-born scientist model: Chi-square (38.97), *df* (18), GFI (.99), NFI (.98), and RMSEA (.064). Foreign-born scientist model: Chi-square (51.41) *df* (18), GFI(.97), NFI (.91), and RMSEA (.011).							

* Note: (1) * p<.10, ** p<.05, *** p<.01 (2) The parentheses are standard errors.

Table 35. Structural differences (productivity: fractional count)

Variables	Collaboration		Grants		Productivity (t_0)		Productivity (t_2)	
	Native-born	Foreign-born	Native-born	Foreign-born	Native-born	Foreign-born	Native-born	Foreign-born
Collaboration			.44*** (.13)	.46* (.35)			.005*** (.002)	.004 (.006)
Grant	.24 (.48)	.88 (.84)					.012*** (.004)	.012** (.007)
Productivity(P_{t0})	3.85*** (1.63)	4.11*** (1.75)	.51 (.85)	1.12** (.68)			.41*** (.042)	.56*** (.081)
Career age	.16** (.084)	-.086 (.11)	.054* (.037)	.12** (.06)	.010*** (.003)	.012*** (.004)	-.0023* (.002)	.001 (.007)
Gender (male=1)	.56 (2.01)	1.96 (1.67)	.14 (1.08)	3.38* (2.35)	.019 (.08)	.011 (.25)	.03 (.057)	.09 (.13)
Top25	1.74 (1.43)	-.37 (.95)	.61 (.74)	2.91*** (1.44)	.081* (.054)	.079 (.14)	.076*** (.038)	.041 (.12)
Research preference	1.13** (.54)	.98* (.69)	-.002 (.30)	.048 (.53)			.024** (.015)	.14*** (.036)
Discrimination	-.045 (1.77)	-.54 (1.25)	1.22 (.96)	.84 (.97)			.028 (.049)	.011 (.034)
Cosmopolitan scale	8.72*** (1.80)	4.25** (2.01)						
Mobility	.082 (1.26)	-1.42** (.80)						
Research center [ERC]			.56 (.86)	.52 (1.38)				
Job satisfaction							.011 (.012)	.043 (.031)
Spouse job							.005 (.042)	.091 (.088)
Non-academic job exp					-.005 (.057)	-.04 (.13)	-.018 (.04)	-.066 (.11)
Engineering	2.30** (1.28)	2.61** (1.56)	.80** (.51)	1.60** (.93)	-.20** (.12)	.24 (.20)	-.42 (.19)	.12 (.09)
Physical sciences	-.59 (.50)	-.73 (.67)	.41 (.35)	.91 (.26)	.41*** (.27)	.34** (.20)	.31** (.19)	.22** (.10)
Bio-life sciences	-2.02** (1.18)	-3.94** (1.86)	-.45* (.27)	-1.29** (.96)	.21** (.11)	.11 (.25)	-.15* (.09)	-.11 (.19)
Computer/math	.96 (.86)	1.22* (.85)	-.77* (.45)	-.82* (.54)	-.47** (.28)	-1.89** (.91)	-.55** (.21)	-.64** (23)
Intercept	-5.58 (8.08)	8.12 (7.56)	-4.11 (3.67)	-5.12 (4.88)	-.23 (.28)	1.25* (.89)	-.13 (.24)	-1.03 (-.86)
R^2	.38	.16	.24	.10	.13	.11	.38	.25
Model Fit Index	US-born scientist model: Chi-square (37.72), *df* (18), GFI (.99), NFI (.98), and RMSEA (.060). Foreign-born scientist model: Chi-square (39.14) *df* (23), GFI (GFI (.97), NFI (.91), and RMSEA (.077).							

Note: (1) * p<.10, ** p<.05, *** p<.01 (2) The parentheses are standard errors.

APPENDIX B.

SAMPLE SELECTION

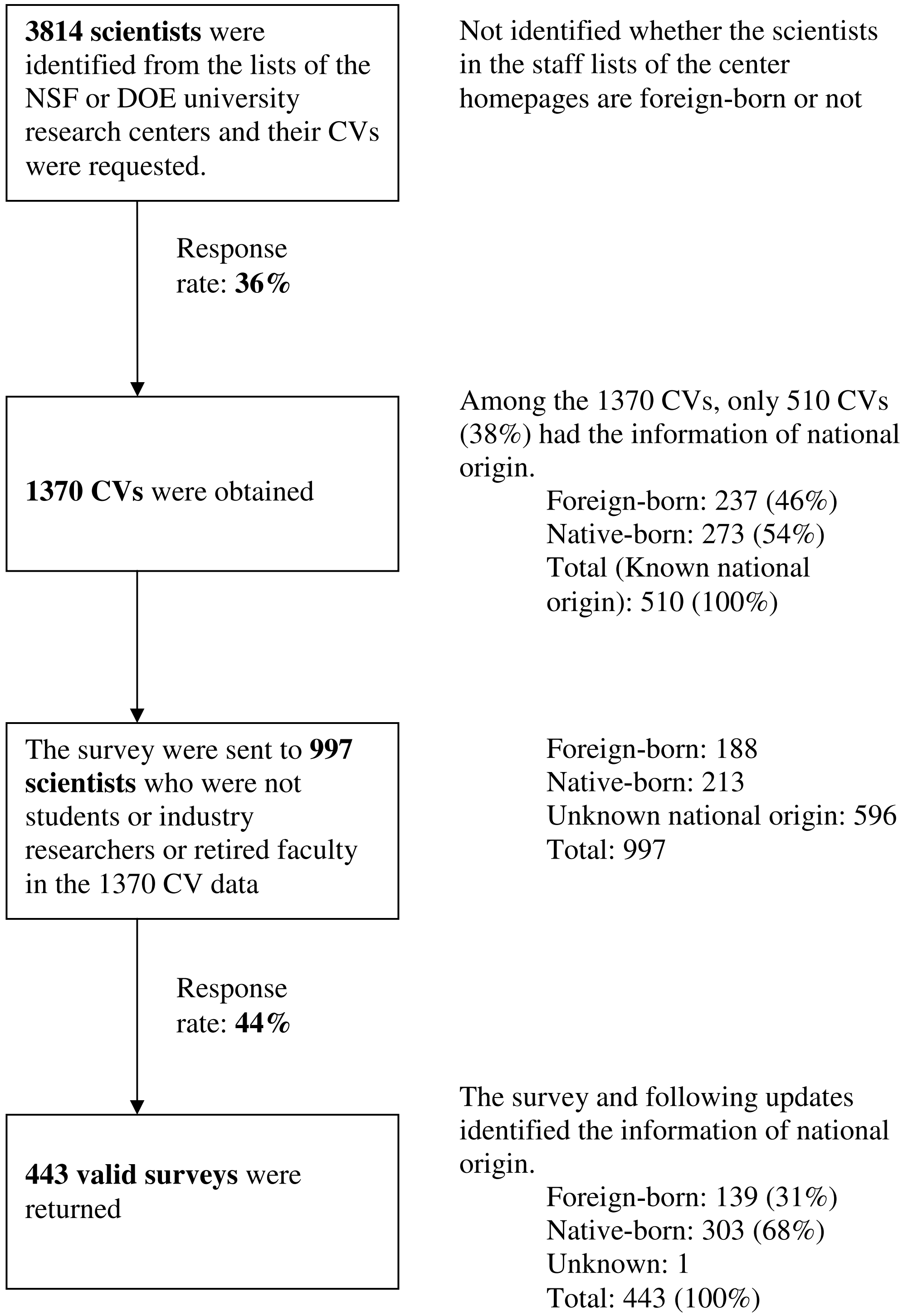


Figure 12. Sample selection process

As shown in Figure 12 in this Appendix B, the RVM data sample selection is consisted of several phases. First, because a complete list of the scientists who were affiliated with 97 NSF university research centers and 2 DOE university research centers was not readily obtainable, the RVM team collected the email addresses of the scientists who were in the staff directories or lists on the research center websites. Each center's home page contained a list of the faculty with basic information such as the e-mail address, telephone number, affiliation, and mailing address. For some centers, the RVM team requested the email addresses by telephone calls. The team collected 3814 scientists' email addresses. In this phase of collecting the list of scientists, it was hard to identify the national origin of the scientists in the research centers. So the proportional sampling for foreign-born scientists was not possible for this study.

Second, the team requested all the 3814 scientists to turn in their most updated CVs. Three follow-up emails were sent to those who did not respond initially. 1370 CVs were finally collected with a response rate of 36% [see Table 36 in Appendix C]. The RVM team coded the CVs with more than 3000 variable categories. Among the 1370 CVs, only 510 CVs (38%) contained the information of national origin; 860 CVs (62%) did not include any information about their nationality. Among the 510 CVs that had national origin information, 237 (46%) scientists were foreign-born and 273% (54%) were native-born scientists.

Third, the RVM team selected 997 scientists who were not students or nonacademic researchers or retired faculty members from the 1370 scientists. Since the survey focused on academic faculty members, graduate students and nonacademic scientists were excluded. Among the 997 scientists, the team identified only 401 scientists' national origin; 188 foreign-born (47%) and 213 native-born scientists (53%).

Fourth, a pre-notice email was sent to the 997 scientists with a request of confirming their office addresses. The survey was mailed to the 997 scientists and three follow-up emails were sent to those who did not respond. 28 scientists requested an electronic version of the survey. The survey strategy was based on the recommendations of Don Dillman (1999). Finally the team received 443 returned surveys; the response rate was 44%. The survey and following updates identified the national origins of the scientists in the sample; 139 (31%) scientists were foreign-born and 303 (68%) scientists were native-born scientists.

The overall sample selection is based on a census rather than on a random sampling strategy. Since the RVM research project dealt with the NSF and DOE university research centers, the sample was selected as many scientists as possible who were affiliated with the research centers. If all the scientists who were affiliated with the NSF or DOE university research centers were in the staff directory of their center's websites, the sample of this study would account for about 12% of all the center-affiliated scientists, and for at least more than 40% of the center-affiliated faculty members [because there is no research center that has only a principal investigator without any graduate student and doctoral collaborators]. In terms of the center affiliated faculty, the percentage seems not so small.

APPENDIX C.

RESEARCH CENTERS AND RESPONSE RATE (CVs)

Table 36. Research centers and Response rate (CVs)

#	Center	Request	Obtain	Unreach -able (Wrong address)	Response Rate
1	Optoelectronic Computing Systems Center (ERC)(Uni. of Colorado-Boulder)	6	4		66.67%
2	Engineering Design Research Center (ERC) (Carnegie Mellon)	5	4		80.00%
3	Institute for Systems Research (Uni. Of Maryland)	15	2		13.33%
4	Microelectronics Research Center - Spring 2000	183	64		34.97%
5	Interconnect Focus Center	64	48		75.00%
6	Center for Neuromorphic Systems Engineering, California Institute of Technology (ERC)	206	53	13	27.46%
7	Center for Emerging Cardiovascular Technologies, Duke University (ERC)	2	2		100.00%
8	Biotechnology Process Engineering Center, Massachusetts Institute of Technology (ERC)	8	6		75.00%
9	Center for Engineered Biomaterials, University of Washington (ERC)	36	14	7	48.28%
10	Center for Engineering of Living Tissues, Georgia Institute of Technology/Emory University (ERC)	5	1		20.00%
11	Center for Environmentally Benign Semiconductor Manufacturing, University of Arizona (ERC)	97	30	3	31.91%
12	Center for Innovation In Product Development, Massachusetts Institute of Technology (ERC)	141	27	18	21.95%
13	Center for Reconfigurable Machining Systems, University of Michigan (ERC)	31	14	3	50.00%
14	Center for Computational Field Simulation, Mississippi State University (ERC)	57	12	2	21.82%
15	Center for Collaborative Manufacuring, Purdue University (ERC)	2	0		0.00%
16	Data Storage Systems Center, Carnegie Mellon University (ERC)	28	17	1	62.96%
17	Center for Telecommunications Research, Columbia University (ERC)	44	10	2	23.81%
18	Center for Low Cost Electronic Packaging, Georgia Institute of Technology (ERC)	47	17	3	38.64%
19	Center for Compound Semiconductor Microelectronics, University of Illinois (ERC)	92	5	29	7.94%

Table 36 (Continued)

#	Center	Request	Obtain	Unreac h-able (Wrong address)	Response Rate
20	Integrated Media Systems Center, University of Southern California (ERC)	25	17	1	70.83%
21	Center for Advanced Technology for Large Structural Systems, Lehigh University (ERC)	7	2		28.57%
22	Center for Particle Science and Technology, University of Florida (ERC)	39	23	4	65.71%
23	Center for Advanced Electronic Materials Processing, North Carolina State University	50	2	16	5.88%
24	Center for Advanced Engineering Fibers and Films, Clemson University (ERC)	25	9	1	37.50%
25	Advanced Combustion Engineering Research Center, Brigham Young University (ERC)	15	10		66.67%
26	Pacific Earthquake Engineering Research (PEER) Center (ERC)	119	42	6	37.17%
27	Mid-America Earthquake (MAE) Center (ERC)	31	13		41.94%
28	Center for Glass Research (Alfred University)	21	10	3	55.56%
29	Center for Steel Making Research (Carnegie Mellon University)	5	2	1	50.00%
30	Center for Advanced Steel Processing and Products Research (Colorado School of Mines)	8	4		50.00%
31	Center for Coatings Research (Eastern Michigan University)	8	4	1	57.14%
32	Center for Polymer Biodegradation (University of Massachusetts)	4	1	2	50.00%
33	Center for Micro-engineered Ceramics (University of New Mexico)	12	6	2	60.00%
34	Center for Energetic Materials (New Mexico Institute of Mining and Technology)	7	2	1	33.33%
35	Center for Engineering Tribology (Northwestern University)	15	9		60.00%
36	Center for Corrosion in Multiphase Systems (Ohio University)	15	3		20.00%
37	Center for Advanced Polymer and Composite Engineering (Ohio State University)	14	8		57.14%
38	Center for Particulate Materials (Pennsylvania State University)	12	6		50.00%
39	Center for Dielectrics (Pennsylvania State University)	36	13	2	38.24%
40	Center for Pharmaceutical Processing Research (Purdue University)	2	0		0.00%

Table 36 (Continued)

#	Center	Request	Obtain	Unreach-able (Wrong address)	Response Rate
41	Center for Biological Surface Science (SUNY at Buffalo/Alfred University/University of Memphis/University of Miami	5	3		60.00%
42	Center for Ergonomics (Texas A & M University)	33	5	17	31.25%
43	Center for Advanced Control of Energy and Power Systems (Arizona State University) Faculty for Entire Dept.	53	19	3	38.00%
44	Center for the Built Environment (University of California, Berkeley)	21	14		66.67%
45	Center for Material Handling Logistics Institute (Georgia Institute of Technology)	41	23	5	63.89%
46	Center for Machine-Tool Systems(University of Illinois)	5	1	1	25.00%
47	Center for Nondestructive Evaluation (Iowa State University)	25	8		32.00%
48	Center for Silicon Wafer Engineering and Defect Science (North Carolina State University)	5	1		20.00%
49	Center for Web Handling (Oklahoma State University)	1	0		0.00%
50	Center for Quality and Reliability Engineering (Rutgers University)	10	6		60.00%
51	Center for Measurement and Control Engineering (University of Tennessee)	12	7		58.33%
52	Center for Hazardous and Toxic Management (New Jersey Institute of Technology/Tufts University)	8	1	3	20.00%
53	Center for Aseptic Processing and Packaging Studies (North Carolina State University/University of California, Davis/Ohio State University	1	0		0.00%
54	Center for Integrated Pest Management (North Carolina State University)	4	1		25.00%
55	Center for Management Information (University of Arizona)	33	5	2	16.13%
56	Center for Optoelectronic Devices, Interconnects, and Packaging (University of Maryland)	7	1	1	16.67%
57	Center for Research of Information Technology and Organizations (University of California, Irvine)	43	15	2	36.59%

Table 36 (Continued)

#	Center	Request	Obtain	Unreach-able (Wrong address)	Response Rate
58	Center for Ultra-High Speed Integrated Circuits and Systems (University of California, San Diego)	21	9		42.86%
59	Center for Sensors and Actuators (University of California, Berkeley)	136	27	13	21.95%
60	Center for the Study of Wireless Electromagnetic (University of Oklahoma)	3	2		66.67%
61	Center for Wireless Information Networks (Rutgers University)	43	14		32.56%
62	Center for Advanced Electronic Materials, Devices and Systems (University of Texas at Arlington)	55	9	6	18.37%
63	Center for the Design of Analog/Digital Integrated Circuits (Washington State University/University of Washington/Oregon State University/SUNY Stony Brook)	15	7	1	50.00%
64	Center for Software Engineering (University of Florida/Purdue University/University of Oregon/West Virginia University)	29	13	1	46.43%
65	Center for Advanced Computing and Communication (North Carolina State University/Duke University)	22	8	1	38.10%
66	Center for Membrane Applied Science and Technology (University of Colorado)	8	3		37.50%
67	Center for Advanced Air Conditioning and Refrigeration (University of Illinois, Urbana)	72	24	12	40.00%
68	Optoelectronic Computing Systems Center (ERC)(Uni. of Colorado-Boulder)	69	28		40.58%
69	Center for Process Analytical Chemistry (University of Washington)	51	20	2	40.82%
70	Center for Behavioral Neuroscience (Emory)	79	46	5	62.16%
71	Center for Microbial Ecology (Michigan State)	45	19	3	45.24%
72	A205Graphics and Visualization Center - (Brown)	31	15	1	50.00%
73	Nanobiotechnology Center (Cornell)	24	10	2	45.45%
74	Center for Analysis and Prediction of Storms (Oklahoma)	32	10	9	43.48%
75	Center for High Pressure Research (SUNY- Stony Brook)	13	2	4	22.22%

Table 36 (Continued)

#	Center	Request	Obtain	Unreach-able (Wrong address)	Response Rate
76	Plant Sensory Systems Network (ERC)(Ohio State Univ.)	13	12		92.31%
77	Sustainability of Semi-Arid Hydrology and Riparian Areas	1	0	1	0.00%
78	Advanced Liquid Crystalline Optical Materials (Case Western Reserve U.)	29	18	1	64.29%
79	Center for Environmentally Responsible Solvents and Processes	119	50	3	43.10%
80	Center for High-Performance Polymeric Adhesives and Composites (Virginia Polytechnic Institute and State University)	19	6	2	35.29%
81	Center for Particle Astrophysics	131	24	40	26.37%
82	Center for Photoinduced Charge Transfer	75	11	32	25.58%
83	Center for Quantized Electronic Structures	65	12	20	26.67%
84	Center for Intelligent Information Retrieval(CIIR)	7	2		28.57%
85	Center for Electronic Imaging Systems (CEIS)	27	11	3	45.83%
86	Center for Low Power Electronics	5	2		40.00%
87	Center for Advanced Friction Studies	6	2		33.33%
88	Institute for Research in Cognitive Science (STC)(U.Penn)	7	7		100.00%
89	Center for Biofilm Engineering (ERC)(Montana State University)	54	14		25.93%
90	Center for Biofilm Engineering (ERC)(Montana State University)	31	2		6.45%
91	Computation and Neural Systems (ERC) (Caltech)	91	13		14.29%
92	Center for Light Microscope Imaging and Biotechnology (STC)(Carnegie Mellon)	66	13	3	20.63%
93	Center for Ultrafast Optical Science (U. Michigan) (STC)	94	45		47.87%
94	Clouds Chemistry and Climate (UCSD) (STC)	2	2		100.00%
95	Center for Biological Timing (U. VA) (STC)	74	32		43.24%

Table 36 (Continued)

#	Center	Request	Obtain	Unreach-able (Wrong address)	Response Rate
96	Center for Synthesis, Growth, and Analysis of Electronic Materials (U.Texas) (STC)	72	28		38.89%
97	James R. Macdonald Laboratory (Kansas State University) (DOE)	22	2		9.09%
98	Microelectronics Research Center (MIRC), Georgia Institute of Technology	146	63		43.15%
99	Interconnect Focus Center (IFC), Georgia Institute of Technology	64	47		73.44%
Total		**3,814**	**1,370**	**320**	**39.21%**

Note: Response Rate = Number of obtained CVs / (Number of scientists to whom a CV was requested - Unreachable)

APPENDIX D.

RVM SURVEY

THE RESEARCH VALUE MAPPING SURVEY: Study of Careers of Scientists and Engineers

The *Research Value Mapping* Survey seeks information about the careers and research experiences of scientists and engineers working in the nation's universities. Our study's purpose is to increase our understanding of the creation of new scientific and technical knowledge.

Please return survey to (postage free):

RESEARCH VALUE MAPPING PROGRAM
Georgia Institute of Technology – School of Public Policy
Atlanta, GA 30332-0345
USA

This study is supported by the National Science Foundation (Grant SBR 98-18229).

***Instructions**: If you cannot provide an exact answer please provide your best estimate. Once you are finished, please fold and staple with return address showing. No postage is necessary. Please check box below if you would like a summary of the results of our study.*

❑ ***Please inform me of results of this study*** **[inform = 1, n=159, 35.3%]**

Section I. Research Collaboration

1. Which of the following describes your <u>current</u> position? [*Please check all that apply*].

- ❑ Tenured faculty **[tenured =1, 278, 61.6%]**
  During what year did you receive tenure? ________

[tenureyr, Year (4 digits), n=261, mean=1989]

- ❑ Tenure track faculty **[tenutrc=1, 72, 16%]**
- ❑ Non-tenure track faculty **[ntenutrc=1, 21, 4.7%]**
- ❑ Research faculty (no formal teaching responsibilities) **[resfacu=1, 38, 8.4%]**
- ❑ Postdoctoral researcher **[postdoc=1, 18, 4.0%]**
- ❑ Research group leader **[rsrchgrp=1, 28, 6.2%]**
- ❑ Line academic administration (e.g. department chair) **[admnstr=1, 30, 6.7%]**
- ❑ Other [*Please specify*] ______________________________________

[othrpost, text, 31, 6.7%]

2. In this section, we define research collaboration as "working closely with others to produce new scientific knowledge or technology." In your <u>current</u> career stage, how important are each of the following factors in your decisions to collaborate? [*Please put an ✗ on the appropriate column*]

	Very Important 4	Somewhat Important 3	Not Important 2	Not Relevant 1	N
Length of time I have known the person **[coldec01]**	60 13.4%	240 53.5%	127 28.3%	22 4.9%	449 100%
Responding to requests of my administrative superiors **[coldec02]**	36 8.1%	105 23.7%	171 38.6%	131 29.6%	443 100%

Interest in helping junior colleagues**[coldec03]**	88 20%	249 56.6%	57 13.0%	46 10.5%	440 100%
Desire to work with researchers who have strong scientific reputations **[coldec04]**	190 42.5%	192 43.0%	58 13.0%	7 1.6%	447 100%
Desire to work with researchers whose work skills and knowledge complement my own (rather than overlap with my skills) **[coldec05]**	363 80.7%	75 16.7%	11 2.4%	1 .2%	450 100%
Quality and value of my previous collaborations with the person **[coldec06]**	345 77.0%	88 19.6%	10 2.2%	5 1.1%	448 100%
Interest in helping graduate students**[coldec07]**	154 34.5%	224 50.1%	48 10.7%	21 4.7%	447 100%
The extent to which working with the individual is fun or entertaining (apart from the work itself) **[coldec08]**	104 23.2%	223 49.8%	99 22.1%	22 4.9%	448 100%
Desire that the collaborator be highly fluent in my language **[coldec09]**	31 7.0%	175 39.2%	179 40.1%	61 13.7%	446 100%
Desire to work with researchers from the same country of origin**[coldec10]**	4 .9%	20 4.5%	292 65.6%	129 29.0%	445 100%
The collaborator should have a strong work ethic**[coldec11]**	227 50.6%	201 44.8%	16 3.6%	5 1.1%	449 100%
The ability of the collaborator to stick to a schedule**[coldec12]**	139 31.0%	272 60.7%	33 7.4%	4 .9%	448 100%
Practices for assigning credit (e.g. order of authorship) **[coldec13]**	60 13.4%	212 47.3%	148 33.0%	28 6.3%	448 100%

3. For the past twelve months, please tell us the number of people in each of the following categories with whom you have had research collaborations:

_______ Male university faculty **[colmale1, n=374, mean = 4.4]**

_______ Male graduate students**[colmale2, 371, 4.0]**

_______ Male researchers who are not university faculty or students**[colmale3, 368, 1.7]**

_______ Female university faculty **[colfema1, 370, 1.2]**

_______ Female graduate students**[colfema2, 370, 1.8]**

_______ Female researchers who are not university faculty or students

[colfema3, 366, .5]

4. While most scientists spend some time working entirely on their own, much work is also performed in research groups. For the past twelve months, could you please estimate the percentage of your research-related work time devoted to each of the following categories [*Note: should add to 100%*].

Percentage of Research Time	Work Setting
16.3%	Working alone (on research that at no point includes a collaborator) **[rschtim1, n=427]**
51.1%	Working with researchers and graduate students in my immediate work group or laboratory**[rschtim2, 441]**
12.1%	Working with researchers in my university, but outside my immediate work group**[rschtim3, 414]**
5.9%	Working with researchers who reside in nations other than the U.S. **[rschtim4, 398]**
9.0%	Working with researchers in U. S. universities other than my own**[rschtim5, 410]**
5.9%	Working with researchers in U. S. industry**[rschtim6, 400]**
3.3%	Working with researchers in U. S. government laboratories**[rschtim7, 387]**

Section II. Grants and Contracts

5. Considering your entire career, have you ever been the principal investigator (PI) for a research grant or contract? [*Please do not include awards from your university or awards for fellowships or traineeships*].

❑ Yes ❑ No **[pi, yes=1, 398, 88.2%, n=444]**

[*If no, please go to question 9, otherwise please go to the next question*].

6. Thinking about your first grant or contract you have been awarded as a PI (if any), please tell us the year awarded, the funding source, the research topic, and the approximate amount and duration of the grant or contract.

Year awarded: _________ **[fstgrnt1, Year(4 digits), n=392, mean=1982]**

Funding source: ____________________________________**[fstgrnt2, text, n=391]**

Research topic: _____________________________________**[fstgrnt3, text, n=386]**

Total amount (approximate) for the duration of the grant or contract:

$_________________ **[fstgrnt4, dollar, n=382, mean=320,813.96]**

Duration: _________ year (s) **[fstgrnt5, # of years, mean=2.9, n=389]**

7. Are you <u>currently</u> a PI on an active grant or contract (from either a private or government source)? [*If not, please go to the next question*].

If so, please tell us the funding source, the research topic, and the amount and duration of the grant or contract. [*Note: If you are PI on more than one active grant or contract, please choose the one you view as most important to your scientific career*].

Funding source: _____________________________________**[cntgrnt1, Text, n=355]**

Research topic: ______________________________________**[cntgrnt2, Text, n=345]**

Total amount (approximate) for the duration of the grant or contract:
$________________**[cntgrnt3, dollar, n=341, mean=2,251,244.58]**

Start year ______ **[cntgrnt4, n=341, 1999]**

End year ______ **[cntgrnt5, n=341, 2003]**

8. During your <u>entire</u> scientific career, approximately how many research proposals have you submitted to government agencies or private sources with you as a principal investigator? Approximately how many have been awarded?

_____ Number submitted **[prpsubm, n=388, mean=31.75]**

_____ Number awarded **[prpawrd, n=389, mean=17.0]**

Section III. Job Selection Criteria and Career Trajectory

9. During what year did you begin in a full time research or faculty position at your current university? [*Do not include time spent, if any, as a student at this university*].

Year _______ **[fullyr, n=440, mean=1988]**

10. When you decided to move to your current university, which of the following were true?
[*Please check all that apply*].

- ❑ I had a faculty job at another university and could have stayed there **[movcur1, yes=1, 120, 26.7%]**
- ❑ I had a faculty job at another university but had been denied tenure (or expected to be denied tenure) **[movcur2, yes=1, 8, 1.8%]**
- ❑ I had a temporary or part-time teaching position at another university **[movcur3, yes=1, 23, 5.1%]**
- ❑ I was a postdoctoral researcher or fellow **[movcur4, yes=1, 96, 21.3%]**
- ❑ I was a graduate student**[movcur5, yes=1, 118, 26.2%]**
- ❑ I had other job offers, but not in universities **[movcur6, yes=1, 38, 8.4%]**
- ❑ I had a job in industry **[movcur7, yes=1, 67, 14.9%]**
- ❑ I had a job in government **[movcur8, yes=1, 21, 4.7%]**
- ❑ I was unemployed **[movcur9, yes=1, 3, .7%]**

11. Regarding your career plans, please indicate the extent to which you agree with each of the following statements. [*Please put an ✗ on the appropriate column*]

	Strongly Agree 4	Agree Somewhat 3	Disagree Somewhat 2	Strongly Disagree 1	N
My chief goal is to obtain a position in the best research institution possible **[carplan1]**	131 30.4%	170 39.4%	78 18.1%	52 12.1%	431 100%
At some point I would be interested in a position in industry**[carplan2]**	19 4.4%	121 27.9%	152 35.1%	141 32.6%	433 100%
I hope to pursue an administrative position in a university**[carplan3]** ❑ Check here if you have had an administrative position in the past but *do not now*. **[carplan4, yes=1, 62, 13.8%]** ❑ Check here if you *now* have an administrative position**[carplan5, yes=1, 93, 20.8%]**	22 5.5%	92 23.1%	142 35.6%	143 35.8%	399 100%

I would be very interested in starting a new company**[carplan6]**	39 9.1%	130 30.3%	124 28.9%	136 31.7%	429 100%
I would be content continuing in a position very much like my current one for the remainder of my career**[carplan7]**	186 42.2%	171 38.8%	54 12.2%	30 6.8%	441 100%
I am seriously considering leaving research altogether**[carplan8]**	9 2.1%	37 8.5%	98 22.5%	292 67.0%	436 100%
I would consider a job in a government laboratory**[carplan9]**	19 4.4%	164 37.6%	126 28.9%	127 29.1%	436 100%

12. We are interested in the factors that motivated you to accept a position at your current university. Please indicate the extent to which the factors below (some personal and family, some professional) were important in making your decision to take a position at your current university. [*Please put an ✗ on the appropriate column*].

	Very Important 4	Somewhat Important 3	Not Important 2	Not Relevant 1	N
Job security (including tenure or tenure prospects) **[motive01]**	122 27.5%	184 41.5%	103 23.3%	34 7.7%	443 100%
Overall quality and reputation of the university**[motive02]**	234 52.5%	189 42.4%	21 4.7%	2 .4%	446 100%
Quality and reputation of my department**[motive03]**	241 54.3%	171 38.5%	25 5.6%	7 1.6%	444 100%
Opportunity to advance in rank**[motive04]**	147 33.3%	191 43.3%	76 17.2%	27 6.1%	441 100%
Quality of students**[motive05]**	197 44.6%	202 45.7%	35 7.9%	8 1.8%	442 100%
Institution's reputation for opportunities for women or minorities**[motive06]**	32 7.2%	122 27.6%	200 45.2%	88 19.9%	442 100%
University's support for my research**[motive07]**	160 36.4%	202 45.9%	58 13.2%	20 4.5%	440 100%
Desire for greater research autonomy**[motive08]**	162 36.7%	148 33.6%	91 20.6%	40 9.1%	441 100%
Desire for less bureaucratic red tape**[motive09]**	80 18.1%	149 33.8%	138 31.3%	74 16.8%	441 100%
Low conflict work environment**[motive10]**	127 28.8%	176 39.9%	93 21.1%	45 10.2%	441 100%

Desire to assume an administrative role **[motive11]**	12 2.7%	35 8.0%	278 63.3%	114 26.0%	439 100%
Employee benefit (e.g. retirement, insurance) **[motive12]**	31 7.0%	191 43.1%	169 38.1%	52 11.7%	443 100%
Salary **[motive13]**	62 14.3%	269 61.8%	84 19.3%	20 4.6%	435 100%
Pursue research with greater industrial applications or industry ties **[motive14]**	46 10.4%	147 33.2%	198 44.7%	52 11.7%	443 100%
Employment opportunities for spouse or partner **[motive15]**	66 15.0%	70 15.9%	164 37.3%	140 31.8%	440 100%
Other family reasons (e.g. live closer to extended family, quality of schools for children, spouse or partner's geographic preference) **[motive16]**	106 24.1%	115 26.2%	125 28.5%	93 21.2%	439 100%
Weather **[motive17]**	37 8.4%	156 35.2%	183 41.3%	67 15.1%	443 100%
Entertainment and leisure opportunities **[motive18]**	36 8.2%	174 39.5%	167 37.9%	64 14.5%	441 100%

Section IV. Work Environment

13. Please indicate the extent to which you agree or disagree with the following statements. [*Please put an ✗ on the appropriate column*].

	Strongly Agree 4	Agree Somewhat 3	Disagree Somewhat 2	Strongly Disagree 1	N
There is nothing as satisfying as doing the best science possible **[wrkenv01]**	222 49.6%	183 40.7%	32 7.1%	11 2.5%	448 100%
Worrying about possible commercial applications distracts one from doing good research **[wrkenv02]**	22 4.9%	136 30.5%	175 39.2%	113 25.3%	446 100%
Generally, I prefer to stick with a research topic rather than move from topic to topic as new interests or opportunities emerge **[wrkenv03]**	41 9.1%	134 29.8%	206 45.9%	68 15.1%	449 100%
The most important mission of scientific research is to improve people's lives in tangible ways **[wrkenv04]**	103 22.9%	221 49.2%	111 24.7%	14 3.1%	449 100%

Government officials should have no role in setting agendas for scientific work**[wrkenv05]**	43 9.6%	132 29.3%	249 55.3%	26 5.8%	450 100%
My own scientific curiosity is the sole consideration in my choice of research topics**[wrkenv06]**	74 16.5%	169 37.6%	174 38.8%	32 7.1%	449 100%
In my immediate work environment scientists are eager to discuss their work with one another**[wrkenv07]**	177 39.3%	214 47.6%	52 11.6%	7 1.6%	450 100%

14. Throughout your career in academia, about how many graduate students, if any, have you supported through your own research funding?

Total number of masters students supported: ________**[spttotl1, n=433, mean=10.5]**

Total number of doctoral students supported: ________ **[spttotl2, n=444, mean=10.8]**

15. How many graduate students, if any, are currently supported through your research funding?

Number of masters students supported currently: __________**[sptcnt1, n=415, mean=1.1]**

Number of doctoral students supported currently: __________**[sptcnt2, n=436, mean=2.8]**

16. Please indicate the extent to which you agree or disagree with the following statements. [*Please put an ✗ on the appropriate column*]

	Strongly Agree 4	Agree Somewhat 3	Disagree Somewhat 2	Strongly Disagree 1	N
I'd rather have a much higher citation rate than a much higher salary **[wrkenv08]**	48 10.9%	180 41.0%	157 35.8%	53 12.1%	439 100%
My scientific work is the most important thing in my life **[wrkenv09]**	37 8.4%	129 29.1%	177 40.0%	100 22.6%	443 100%
I feel that I am now (or soon will be) a leading researcher in my field**[wrkenv10]**	131 29.9%	213 48.6%	70 16.0%	24 5.5%	438 100%
My colleagues in this department	145	240	44	13	442

appreciate my research contributions**[wrkenv11]**	32.8%	54.3%	10.0%	2.9%	100%
I am satisfied with my job**[wrkenv12]**	197 44.6%	194 439.9%	47 10.6%	4 .9%	442 100%
I am satisfied with my personal life (i.e. everything *other* than the job) **[wrkenv13]**	224 50.7%	157 35.5%	56 12.5%	5 1.1%	442 100%
At my current institution, I am discriminated against on the basis of my sex**[wrkenv14]**	4 .9%	20 4.5%	48 10.9%	368 83.6%	440 100%
At my current institution, I am discriminated against on the basis of my race, ethnicity, religion, or national origin**[wrkenv15]**	2 .5%	18 4.1%	44 10.0%	375 85.4%	439 100%
My family is more important to me than my work**[wrkenv16]**	223 50.9%	146 33.3%	60 13.7%	9 2.1%	438 100%
The best reason for funding research is the social benefits it provides**[wrkenv17]**	49 11.3%	161 37.1%	176 40.6%	48 11.1%	434 100%
I think I am paid about what I am worth in the academic market**[wrkenv18]**	70 15.9%	207 47.0%	124 28.2%	39 8.9%	440 100%
I am more interested in developing fundamental knowledge than in the near-term economic or social applications of science and technology**[wrkenv19]**	117 26.4%	167 37.7%	139 31.4%	20 4.5%	443 100%

Section V. Demographic Characteristics

17. Are you: ❑ Male ❑ Female **[gender, male=1, male=391 (87.1%), female=58, missing=2]**

18. Currently, are you either married or living with a domestic partner?

❑ Yes ❑ No [*Go to Question 20*] **[marital, yes=1, 402, 90.1%]**

19. Which of the following best describes your spouse or partner's current position?

- ❑ Full time homemaker or family caregiver **[spouhome, yes=1, 131, 29.1%]**
- ❑ Professional (e.g. lawyer, physician, accountant) **[spouprof, yes=1, 98, 21.8%]**
- ❑ Private business or self-employed **[spoupriv, yes=1, 52, 11.6%]**
- ❑ Government or nonprofit employee **[spougovt, yes=1, 12, 2.7%]**
- ❑ Student **[spoustud, yes=1, 13, 2.9%]**
- ❑ Tenured or tenure track university or college faculty **[spoutenu, yes=1, 32, 7.1%]**
- ❑ Non-tenure track university or college faculty [**spounont, yes=1, 13, 2.9%]**
- ❑ University research position **[spouures, yes=1, 12, 2.7%]**
- ❑ Other university position [**spouuniv, yes=1, 22, 4.9%]**
- ❑ Other [*Please specify*] ________________________________ **[spouothr, text, 30]**

20. Currently, do you have children living with you as part of your family? If so, how many?

Number of children living with you: _________ **[children, n=419, mean=1]**

21. What year were you born? 19_____ **[bornyr, n=426, mean=1954]**

22. What is the discipline of your doctoral degree (e.g. physics, chemistry, electrical engineering), and when did you obtain your doctoral degree?

Discipline of doctoral degree:
____**[disciple, n=438]**

❑ Check here if you do not have a doctoral degree **[doctdumm, check=1, 12, 2.7%]**

Year doctoral degree obtained: ___________ **[degryr, n=439, mean=1983]**

Current field of research: ___________________________________ **[field, n=436]**

23. What is your current citizenship status?

- ❑ Native born U. S. citizen **[uscit, yes=1, 308, 68.4%]**
- ❑ Naturalized U. S. citizen [**natuscit, yes=1, 62, 13.8%]**

- ❑ Non U. S. citizen with a permanent U. S. resident visa **[pmtvisa, yes=1, 57, 12.7%]**
- ❑ Non U. S. citizen with a temporary U. S. resident visa [**tempvisa, yes=1, 17, 3.8%]**

24. [*IF NON U. S. CITIZEN OR NATURALIZED CITIZEN*], of which country are (were) you a citizen?

____ **[country, n=108]**

25. If you have any additional comments or questions, please write them below.

___

___

Thank you for your time and assistance with this study. Please fold and staple with return address showing before placing in the mail. No postage is necessary.

APPENDIX E.

APPLICATION OF STRUCTURAL EQUATIONAL MODELING

This technical note discusses the issues in applying SEM for this study, such as model specification, sample size, identification, treatment of construct, and instrumental variables.

1. Model specification:

The main reason to use SEM is to deal with the reciprocal relationship among collaboration, grants, and productivity. The relationship and direction are specified in the previous section (see Figure 1 in section 4.2).

2. Sample size in SEM:

According to the rule of thumb (Kline, 1998), the sample size that is larger than 200 would be good enough, but in some cases, a smaller sample than 200 (e.g., 100) is also allowed with some precautions. The whole model (in section 6.5) has a sample of 406. But in the subgroup analysis (in section 6.6), the foreign-born models have only a sample of 113. In addition, the ratio of the number of subjects to the number of model parameters should be 10:1, or at least 5:1 (Kline, 1998). In both the sample size and the ratio of subjects to parameters, the interpretation of the foreign-born only model (section 6.6) should be carefully treated.

3. Identification:

Identification is often the most important issue in applying SEM, particularly a non-recursive model. It should meet necessary and sufficient conditions (Kline, 1998). First, the necessary condition requires that the number of parameters should be smaller than that of observations, and that the order condition should be satisfied. The order condition is that the number of excluded variables should be one less than the number of endogenous variables. If the order condition is not satisfied, the model is under-identified, in other words, not identified. The order condition is necessary but not sufficient.

(1) Parameter < observations
Observations: (21*22)/2 =231
Parameters: 21 variables + 53 direct effects + 4 disturbance terms + 136 exogenous covariance = 214

(2) Order conditions
Collaboration = the number of excluded variables (4) ≥ one less than the number of endogenous variables (3)

Grants = the number of excluded variables (5) ≥ one less than the number of endogenous variables (3)

Productivity (Pt_0) = the number of excluded variables (8) ≥ one less than the number of endogenous variables (3)

Productivity (Pt_2) = the number of excluded variables (3) ≥ one less than the number of endogenous variables

As seen in the above, the necessary condition is met because the number of excluded variables in each equation are equal to or larger than 3 (one less than the number of endogenous variables).

Second, the sufficient condition addresses the rank condition (Kline, 1998, p.157). Endogenous variables involved in a feedback loop need a unique pattern of direct effects from variables outside the loop. The rank of the system matrix must be at least one less than the number of endogenous variables. Rank ≥ (#Endogenous variables – 1). The exogenous variables that are not related to all the endogenous variables are included in the below table. “1” means “specified as having an association” and “0” means “not specified as having an association.” By using this matrix, all the endogenous variables have 3 ranks (the number of remaining rows after deleting “1” columns), which meets the rank condition.

↓	Collab	Grants	Res pref	Discrimin	Cosmo	Mobility	Res center	Job satis	Spouse	Nonacademic
Colla	1	1	1	1	1	1	0	0	0	0
Grant	1	1	1	1	0	0	1	0	0	0
Prd 0	0	0	0	0	0	0	0	0	0	1
Prd 2	1	1	1	1	1	0	0	1	1	1

4. Treatment of latent variables

The reciprocal model has three latent exogenous variables such as research preference, discrimination, and job satisfaction. These latent variables were created by combining the scores in each question items. Research preference is based on two question items such as “my scientific work is the most important thing in my life” and “there is nothing as satisfying as doing the best science possible.” Job satisfaction has three question items such as “I am satisfied with my job,” “My colleagues in this department appreciate my research contributions,” and “I think I am paid about what I am worth in the academic market.” Discrimination has only one item, “At my current institution, I am discriminated against on the basis of my race, ethnicity, religion, or national origin.”

Ideally a latent variable (factor) should have three or more indicators. But discrimination and research preference have only one and two indicators. This does not provide a proper test for the measurement model. Considering this weakness, this study uses the combined scores for each latent variable, not the factorized standardized coefficients. This solution inherently contains a measurement error problem as long as the combined scores (or index) are not confirmed theoretically.

5. Instrumental variables:

In the modified model (Figure 3), only collaboration and grants have a reciprocal relationship. Cosmopolitan scale and mobility play a role as instrumental variables for collaboration in the collaboration → grants relationship, because cosmopolitan scale and mobility is correlated with collaboration but do not directly cause grants. Likewise, research center (ERC-affiliation) is an instrumental variable for grants in the grants → collaboration relationship, because it is correlated with grants but does not directly cause collaboration. In the meantime, non-academic job experience is an instrumental variable for productivity, because it is correlated with productivity but does not directly cause collaboration and grants.

REFERENCES

Adams, James D., Grant C. Black, Roger Clemmons, and Paula E. Stephan (2003) Patterns of Research Collaboration in U.S. Universities, 1981-1999. AAAS Meetings Denver, Colorado February 18, 2003.

Ajiferuke, I, Q. Burell, and J. Tague (1988) Collaborative Coefficient: A Single Measure of the Degree of Collaboration in Research. *Scientometrics*, 14(5): 421-433

Allison, Paul D. and J. Scott Long (1990) Departmental Effects on Scientific Productivity, *American Sociological Review*, 55: 469-478.

Altbach, Philip (2004) In Race for International Students, US Erects Hurdles and Loses Out. *Christian Science Monitor*, March 16, 2004 edition

American Association of University Professors (AAUP) (2003) Academic Freedom and National Security in a Time of Crisis. A Report of the AAUP Special Committee. *ACADEME*, 89 (6): 34-59

Anderson, S (1996) The Wage and Employment Impact of Immigrant Scientists and Engineers in High Technology. *International Educator*, NAFSA: Association of International Educators.

Arnone, Michael (2004) New Survey Confirms Sharp Drop in Applications to U.S. Colleges from Foreign Graduate Students, *The Chronicle of Higher Education*, March 4, 2004.

Arora, Ashish and Alfonso Gambardella (1996) The Impact of NSF Support for Basic Research In Economics. IDEAS working paper.

Astin, H. S. (1969) *The Women Doctorate in America*. New York, Russell Sage Foundation.

Astin, Alexander W. and Lewis G. Solmon (1981) Are Reputational Ratings Needed to Measure Quality? *Change* 13(10): 14-19.

Atkinson, R.C. (1990) Supply and Demand for Scientists and Engineers: A National Crisis in the Making (in Association Affairs) *Science*, 248: 425-432.

Babu, A. Ramesh and Y.P. Singh (1998) Determinants of Research Productivity, *Scientometrics*, 43 (3): 309-29.

Ballou, Janice, Matthew Mishkind, Geraldine Mooney and Welmoet van Kammen (2002) *National Science Foundation Report on Efficiency of Grant Size and Duration*. National

Science Foundation, Chief Budget and Systems, Operations and Budget Branch. Arlington, VA.

Bauer, T, Lofstrom, M, and Zimmermann, K (2000) *Immigration Policy, Assimilation of Immigrants and Natives' Sentiments towards Immigrants: Evidence from 12 OECD-Countries.* Discussion Paper No. 187, August 2000. The Institute for the Study of Labor (IZA).

Bayer, Alan E. and John C. Smart (1991) Career Publication Patterns and Collaborative "Styles" in American Academic Science. *Journal of Higher Education*, 62(6): 613-636.

Beaver, D and Rosen, R (1979) Studies in Scientific Collaboration: Part II-Scientific Co-authorship, Research Productivity and Visibility in the French Scientific Elite, 1799-1830, *Scientometrics*, 1 (1): 133-149.

Becker, Gary (1993) *Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education.* 3rd Ed, Chicago, University of Chicago Press.

Bellas, Marcia L. and Robert K. Toutkoushian (1999) Faculty Time Allocations and Research Productivity: Gender, Race, and Family Effects, *The Review of Higher Education,* 22 (4): 367-90.

Benowitz, Steven (1997) Early-Career Awards Giving New Researchers A Leg Up. *The Scientist*, May 26, 11(11): 13.

Biglan, A (1973) Relationships between Subject Matter Characteristics and the Structure and Output of University Departments, *Journal of Applied Psychology,* 57 (3): 204-213.

Black, Grant and Paula Stephan (2003) The Importance of Foreign Ph.D. Students to U.S. Science, In *Science and the University*, Ronald Ehrenberg and Paula Stephan (eds). University of Wisconsin Press, forthcoming.

Blackburn, Robert T., Bieber, J. P., Lawrence, J. H., and L.C. Trauvetter (1991) Faculty at Work: Focus on Research, Scholarship and Service. *Research in Higher Education*, 32: 385-413.

Blackburn, Robert T., C.E. Behymer, and D.E. Hall (1978) Research Note: Correlates of Faculty Publications. *Sociology of Education*, 51:132-141.

Blackburn, Robert T. and Janet H. Lawrence (2003) *Faculty at Work: Motivation, Expectation, Satisfaction.* Johns Hopkins University Press

Bollag, Burton (2004a) Wanted: Foreign Students. *The Chronicle of Higher Education*, October 8, 2004.

Bollag, Burton (2004b) Foreign Enrollments at American Universities Drop for the First Time in 32 Years. *The Chronicle of Higher Education*, November 10, 2004.

Bonzi, Susan (1992) Trends in Research Productivity Among Senior Faculty, *Information Processing & Management*, 28 (1): 111-20.

Borjas, George (1985) Assimilation, Changes in Cohort Quality, and the Earnings of Immigrants. *Journal of Labor Economics*. 3: 463-489.

Borjas, George J (1994) The Economics of Immigration. *Journal of Economic Literature* 32: 1667-1717.

Borjas, George (2000) Foreign-Born Teaching Assistants and the Academic Performance of Undergraduates. *American Economic Review,* May 2000, 355-359.

Borjas, George (2002) An Evaluation of Foreign Student Program. *Backgrounder*, Center for Immigration Studies, June 2002, 1-11.

Borjas, George (2004) Immigration in High-Skill Labor Markets: The Impact of Foreign Students on the Earnings of Doctorates, April 2004. (http://www.nber.org/~sewp/events/2004.05.28/Borjas_The_Impact_of_Foreign_Students.pdf)

Bouvier, Leon F. and David Simcox (1994) *Foreign-Born Professionals in the United States.* Washington DC: Center for Immigration Studies.

Bouvier, Leon F. and J. Martin (1995) *Foreign-born Scientists, Engineers and Mathematicians in the United States.* Washington DC: Center for Immigration Studies.

Bozeman, Barry and Craig Boardman (2003) *Managing the New Multidiscipline, Multipurpose University Research Centers.* Washington, DC, IBM Endowment for the Business of Government.

Bozeman, Barry, James Dietz, and Monica Gaughan (2001) Scientific and Technical Human Capital: an Alternative Model for Research Evaluation. *International Journal of Technology Management,* 22 (8): 616–630.

Bozeman, Barry and Elizabeth Corely (2004) Scientists' Collaboration Strategies: Implications for Scientific and Technical Human Capital. *Research Policy,* 33(4): 599-616.

Brouthers, K. and L. Brouthers (2001) Explaining the National Cultural Distance Paradox. *Journal of Internaional Business Studies,* 32(1): 177-189.

Bryant, LeEarl A (2002) Trying Times for U.S. Engineers. The Institute of Electrical and Electronics Engineers (IEEE-USA). Pan Organizational Summit on the U.S. Science and Engineering Workforce. November 12, 2002.

Cameron, Susan W. and Robert T. Blackburn (1981) Sponsorship and Academic Career Success. *Journal of Higher Education,* 52(4): 369-377.

Cannon, Peter (1988) Foreign Engineers in U.S. Industry: An Exploratory Assessment (p105-124) in *Foreign and Foreign-born Engineers in the United States: Infusing Talent, Raising Issues,* ed. National Research Council. Washington DC: National Academy Press.

Carliner, Geoffrey (1980) Wages, Earnings, and Hours of First, Second, Third Generation American Males. *Economic Inquiry,* 18(1): 87-102.

Carliner, Geoffrey (2000) The Language Ability of U.S. Immigrants: Assimilation and Cohort Effects. *International Migration Review,* 34(1): 158-183.

Chen, Shin-Horng (1997) Decision-making in Research and Development Collaboration. *Research Policy*, 26: 121-135.

Chiswick, Barry R (1978) The Effect of Americanization on the Earnings of Foreign-born Men. *Journal of Political Economy,* 86(5): 897-921.

Chiswick, Barry R (1992) (ed) *Immigration, Language, and Ethnicity: Canada and the United States.* Washington: American Enterprise Institute.

Chiswick, Barry R and P. Miller (1995) The Endogeneity Between Language and Earnings: An international analysis. *Journal of labor economics,* 13: 204-246

Chiswick, Barry R. and Paul W. Miller (1998) English Language Fluency Among Immigrants in the United States, *Research in Labor Economics*, 17: 151-200.

Chiswick, Barry R (1999) Are Immigrants Favorably Self-Selected? *The American Economic Review*, 89 (2): 181-185

Choi, Charles Q (2004) Scientists' US visas delayed. *The Scientists,* February 26, 2004

Choi, Hyaeweol (1995) *An International Scientific Community: Asian Scholars in the United States.* Praeger. Westport, Connecticut.

Chubin, Daryl E. and Ed Hackett (1990) *Peerless Science: Peer Review and U.S. Science Policy*. Albany, State University of New York Press.

Clemente, Frank (1973) Early Career Determinants of Research Productivity, *American Journal of Sociology*, 79 (2): 409-19.

Cole, Jonathan (1979) *Fair science: Women in the Scientific Community.* New York, Free Press.

Cole, Jonathan (1981) Women in Science. *American Scientist*, 69:385-391.

Cole, Jonathon and Stephan Cole (1973) *Social Stratification in Science.* Chicago: University of Chicago Press.

Cole, Jonathan and H. Zuckerman (1984) The productivity puzzle: Persistence and change in patterns of publication of men and women scientists, In M. W. Steinkamp and M. L. Maehr (eds), *Advances in Motivation and Achievement.* JAL, Greenwich Conn, 217-256.

Cole, Stephan (1976) Age and Scientific Performance. *American Journal of Sociology*, 84: 958-977.

Cole, Stephan (1992) *Making Science: Between Nature and Society*. Chicago, University of Chicago Press

Cole, Stephen and Jonathan R. Cole (1967) Scientific output and recognition: a study in the operation of the reward system in science, *American Sociological Review,* 32 (3): 377-90.

COSEPP (2000) *Enhancing the Postdoctoral Experience for Scientists and Engineers,* A Guide for Postdoctoral Scholars, Advisors, Institutions, Funding Organizations, and Disciplinary Societies. Committee on Science, Engineering, and Public Policy, National Academy of Sciences, Washington, DC, National Academy Press.

Coverman, Shelley (1989) Women's work is never done: The division of domestic labor. Jo Freeman (eds), *Women: A Feminist Perspective*, 4th Ed. Mountain View, CA: Mayfield.

Cox, Taylor (1993) *Cultural Diversity in Organizations: Theory, Research and Practice.* San Francisco, Berret-Koehler.

Crane, Diana (1965) Scientists at Mjor and Minor Universities: A Study of Productivity and Recognition, *American Sociological Review*, 30 (5): 699-714.

Creamer, E. G. (1998) The Scholarly Productivity of Women Academics. *Initiatives,* 57(1): 1-9.

CRIS International (2001) *German Scientists in the United States: Challenges for Higher Education and Science Policies.* Center for Research on Innovation & Society.

Dey, Eric L, Jeffrey F Milem, and Joseph B. Berger (1997) Changing patterns of Publication Productivity: Accumulation Advantage or Institutional Isomorphism? *Sociology of Education.* 70 (4): 308 -324.

Dietz, James et al (2000) Using the curriculum vita to study the career paths of scientific and engineers: An exploratory assessment. *Scientometrics.* 49(3): 419-442.

Dietz, James S (2004) *Scientists and Engineers in Academic Research Centers – An Examination of Career Patterns and Productivity.* Doctoral Dissertation, Georgia Institute of Technology, February 2004.

Dillman, Don (1999) *Mail and Internet Surveys: The Tailored Design Method*, 2nd Edition, New York, John Wiley Company.

DiTomaso, Nancy, George F. Farris and Rene Cordero (1993) Diversity in the technical work force: Rethinking the management of scientists and engineers, *Journal of Engineering and Technology Management,* 10 (1-2): 101-127.

Drew, David Eli (1985) *Strengthening Academic Science.* New York, Praeger.

Dundar, H. and D. Lewis (1998) Determinants of Research Productivity in Higher Education. *Research in Higher Education,* 39(6): 607.

Durden, G. and Perri, T (1995) Coauthorship and Publication Efficiency. *Atlantic Economic Journal,* 23(1): 69-76.

Dustmann, Christian (1994) Speakin fluency, writing fluency and earnings of migrants. *Journal of Population Economics,* 7: 133-156.

Dustmann, Christian (1998) Temporary migration, human capital, and language fluency of migrants. Mimeo.

Dustmann, Christian and Francesca Fabbri (2002) Language Proficiency and Labour Market Performance of Immigrants in the UK. Mimeo .

Dustmann, Christian and Arthur van Soest (2001) Language Fluency and Earnings: Estimation with Misclassified Language Indicators. *Review of Economics and Statistics,* 83(4): 663-674.

Espenshade, Thomas J. and Haishan Fu (1997) An analysis of English-language proficiency among U.S. immigrants. *American Sociological Review.* 62 (2): 288-305.

Espenshade, Thomas J. and German Rodriquez (1997) Completing the Ph.D: Comparative Performances of US and Foreign Students. *Social Science Quarterly,* 78(2): 593-605.

Fechter, Alan and Michael S. Teitelbaum (1997) A Fresh Approach to Immigration. *Issues in Science and Technology,* Spring 1997.

Finkelstein, M.J. (1984) *The American academic profession: a synthesis of social scientific inquiry since World War II*. Columbus, Ohio State University Press.

Finn, Michael (1988) Foreign Engineers in the U.S. Labor Force. In National Research Council, *Foreign and Foreign-born Engineers in the United States: Infusing Talent, Raising Issues,* Office of Scientific and Engineering Personnel (OSEP). Washington DC: National Academy Press, 91-104

Finn, Michael (2003) *Stay Rates of Foreign Doctorate Recipients From U.S. Universities.* Oak Ridge, TN: Oak Ridge Institute for Science and Education.

Fox, Mary Frank (1983) Publication Productivity among Scientists: A Critical Review. *Social Studies of Science,* 13: 285-305.

Fox, Mary Frank and Catherine A. Faver (1984) Independence and Cooperation in Research: The Motivations and Costs of Collaboration. *Journal of Higher Education,* 55: 347-359.

Fox, Mary Frank (1992a) Research, Teaching, and Publication Productivity: Mutuality Versus Competition in Academia. *Sociology of Education,* 65(4): 293-305.

Fox, Mary Frank (1992b) Research Productivity and the Environmental Context. In T. G. Whiston & R. L. Geiger (eds), *Research and Higher Education: The United Kingdom and the United States.* London: S.R.H.E.

Fulton, O. and M. Trow (1974) Research Activity in American Higher Education. *Sociology of Science*, 47: 29-73.

Galbraith, J. and L. L. Cummings (1967) An Empirical Investigation of the Motivation Determinants of Task Performance. *Organizational Behavior and Human Performance,* 2: 237-257.

Garber, Phil (1988) When Language Hurts Scientists and Their Employees. *The scientist,* 2(15).19 Aug, 08. 1988

Gaughan, Monica and Barry Bozeman (2002) Using curriculum vitae to compare some impacts of NSF research grants with research Center funding. *Research Evaluation,* 11 (1): 17-26.

Geisler, E and A. Rubenstein (1989) *University-Industry Relations: A Review of Major Issues, Cooperative Research and Development: the Industry, University, Government Relationship.* Norwell. Kluwer Academic Publishers.

Glanz, James (2003) Study warns of lack of scientists as visa application drop. *New York Times*, Section A P. 28, November 20, 2003.

Godin, Benoit (2003) The impact of research grants on the productivity and quality of scientific research. *INRS.* 2003.

Goodwin, Crauford D. and Michael Nacht (1983) *Absence of Decision: Foreign Students in American Colleges and Universities: A report on policy formation and the lack thereof.* Institute for International Education, New York.

Gordon, Michael (1980) A Critical Reassessment of Inferred Relations between Multiple Authorship, Scientific Collaboration, the Production of Papers and Their Acceptance for Publication. *Scientometrics,* 2:193-201.

Gorman, Anne M. and Marguerite M. Scruggs (1984) Characteristics of Home Economics Researchers. *Home Economics Research Journal,* 12(4): 461-469.

Greenwood, M.R.C. and D.G. Riordan (2002) Research Universities in the New Security Environment. *Issues in Science and Technology Online,* Summer 2002.

Grubel, H.G. and A. D. Scott (1966) The Immigration of Scientists and Engineers to the United States, 1949-61. *The Journal of Political Economy,* 74 (4): 368-378.

Grunig, Stephen D (1997) Resources, Reputation, and Research: The Effect of Research Activity on Perceptions of Undergraduate Education and Institutional Resource Acquisition. *Journal of Higher Education,* 68:17-52.

Hackett, Edward J. (1987) Funding and Academic Research in the Life Sciences: Results of an Exploratory Study. *Science & Technology Studies,* 5 (¾): 134-147.

Hagstrom, W.O., 1965. *The Scientific Community*. New York, Basic Books.

Ham, R.M., and D.C. Mowery (1998) Improving the Effectiveness of Public-Private R&D Collaboration: Case Studies at a U.S. Weapons Laboratory. *Research Policy,* 26(6): 661-675.

Hamovitch, W. and R. D. Morgenstern (1977) Children and the Productivity of Academic Women. *Journal of Higher Education,* XLVII: 633-645.

Hara, Noriko, Paul Solomon, Seung-Lye Kim, and Diane H. Sonnenwald (2003) An emerging view of scientific collaboration: scientists' perspectives on collaboration and factors that impact collaboration. *Journal of the American Society for Information Science and Technology,* 54(10):952-965.

Hargens, L. (1975) *Patterns of Scientific Research: A Comparative Analysis of Research in Three Scientific Fields.* The ASA Rose Series in Sociology.

Heffner, A. G. (1981) Funded Research, Multiple Authorship, and Subauthorship Collaboration in Four Disciplines, *Scientometrics,* 3 (1): 5-12.

Henry, Shannon (2002) INS Sees Big Drop in High-Tech Visas. *The Washington Post,* Aug 16, 2002. E.05.

Hess, D.J. (1995) *Science and Technology in a Multicultural World: the Cultural Politics of Facts and Artifacts.* New York. Columbia University Press.

Hexter, J. H. (1995) *The Judaeo-Christian Tradition*, 2nd Ed. Yale University Press.

Heylin, Michael (1992) Foreign-born Chemists Ponder Career Prospects, *Chemical & Engineering News,* Washington, June 1, 1992, 37-38.

Hicks, Diana and Sylvan Katz (1996) Where Is Science Going? *Science, Technology, & Human Values,* 21 (4): 379-406.

Hofstede, Geert (1980) *Culture's Consequences : International Differences in Work-Related Values,* Cross Cultural Research and Methodology Series, vol 5, Sage Publications.

Hollis, Aidan (2001) Co-authorship and the Output of Academic Economists. *Labour Economics,* 8: 503-530.

Holmstrom, Engin, Catherine Gaddy, and Virginia Van Horne (1997) Is There a Brain Drain from Science and Engineering? *Issues in Science and Technology,* Spring 1997, 86-87.

Human Resources Development Canada (1999) *International Migration of Skilled Workers: Facts and Factors.* December 1999. Industry Canada.

Jencks, Christopher and David Riesman (1969) *The Academic Revolution.* New York, Anchor.

Johnson, Jean M. and Mark C. Regets. (1998) *International Mobility of Scientists and Engineers to the United States – Brain Drain or Brain Circulation?* Issue Brief, Division of Science Resources Studies, NSF 98-316 (June 22).

Kanter, R. (1993) *Men and Women of the Corporation.* New York, Basic Books.

Katz, J.S. (1994) Geographical Proximity and Scientific Collaboration. *Scientometrics*, 31(1): 31-43.

Katz, Sylvan J and Martin, Ben R (1997) What is Research Collaboration? *Research Policy.* 26 (1): 1-18.

Kelly, Maureen E. and Robert J. Warmbrod (1986) Developing and Maintaining Productive Researchers in Agricultural Education. *Journal of the American Association of Teacher Educators in Agriculture*, 27(1): 27-32.

Kingsley, G., B. Bozeman, and K. Coker (1996) Technology Transfer and Absorption: an 'R&D Value-Mapping' Approach to Evaluation. *Research Policy,* 25: 967-995.

Kline, Rex B. (1998) *Principles and Practices of Structural Equation Modeling*. New York, The Guilford Press.

Knorr-Cetina, K. (1999) *Epistemic Cultures: How the Sciences Make Knowledge.* Cambridge, Harvard University Press.

Kossoudji, Sherrie A (1988) English Language Ability and the Labor Market Opportunities of Hispanic and East Asian Immigrant Men. *Journal of Labor Economics,* 6: 205-228.

Kraut, R.E., J. Galegher, and C. Egido (1987) Relationships and Tasks in Scientific Research Collaboration. *Human-Computer Interaction*, 3:31-57.

Kusa, Glenn W. (1988) Effect of Foreign Nationals on Federally Supported Laboratories. In *Foreign and Foreign-born Engineers in the United States: Infusing Talent, Raising Issues,* National Research Council. National Academy Press, Washington, D.C. 147-162.

Kyvik, Svein and Teigen, Mari (1996) Child Care, Research Collaboration, and Gender Differences in Scientific Productivity. *Science, Technology, & Human Values,* 21 (1): 54-71.

LaFollette, M.C. (1992) *Stealing into Print.* Berkeley, University of California Press.

Landry, R., Traore, N., and Godin, B. (1996) An Economic Analysis of the Effect of Collaboration on Academic Research Productivity. *Higher Education.* 32: 1-19.

Landry, R. and Nabil Amara (1998) The Impact of Transaction Costs on the Institutional Structuration of Collaborative Academic Research. *Research Policy*, 27: 901-913.

Lawani, S. (1986) Some Bibliometric Correlates of Quality in Scientific Research. *Scientometrics*, 9:13-25.

Lawrence, Janet H. and Robert T. Blackburn (1988) Age as a Predictor of Faculty productivity: Three Conceptual Approaches, *Journal of Higher Education,* 59(1): 22-38.

Lederberg, J and Uncapher, K (1989) *Towards a National Collaboratory Report of an Invitational Workshop at the Rockefeller University.* Washington, D.C. National Science Foundation, Directorate for Computer and Information Science and Engineering.

Lee, Sooho and Barry Bozeman (2004) The Impact of Research Collaboration on Research Productivity. *Social Studies of Science*, forthcoming.

Lehman, H. (1953) *Age and Achievement.* Princeton, Princeton University Press.

Lerner, Joshua and Rustum Roy (1984) Numbers, Origins, Economic Value, and Quality of Technically Trained Immigrants into the United States. *Scientometrics* 6(4): 243-259.

Levin, S. G. and Stephan, P.E. (1991) Research Productivity over the Life Cycle: Evidence for Academic Scientists. *American Economic Review,* 81: 114-132.

Levin, S. G. and Stephan, P.E. (1999) Are the Foreign-born a Source of Strength for U.S. Science? *Science,* 285: 1213-1214.

Levin, S.G., Stephan, P.E. and Winkler, Anne E (2000) Imported brains in science and engineering: employment consequences for U.S.-citizens, Paper prepared for presentation at the conference on Migration and Development. Office of population research. Princeton Univ. May4-6, 2000.

Liebert, Roland J. (1976) Productivity, Favor, and Grants Among Scholars. *The American Journal of Sociology,* 82 (3):664-673.

Liebert, Roland J. (1977) Research-Grant Getting and Productivity among Scholars: Recent National Patterns of Competition and Favor, *Journal of Higher Education,* 48 (2): 164-92.

Leiman, Lima (2004) Should the Brain Drain Be Plugged? A Behavioral Economics Approach. *Texas International Law Journal*, 39 (4): 675 – 696.

Lin, Minwei and Barry Bozeman (2004) Researchers' Industry Experience and Productivity in University-Industry Research Centers: A "Scientific and Technical Human Capital" Explanation. Manuscript, RVM Program.

Lindsey, Duncan (1980) Production and Citation Measures in the Sociology of Science: the Problems of Multiple Authorship. *Social Studies of Science.* 10: 145-162.

Long, J. Scott (1978) Productivity and Academic Positions in the Scientific Career, *American Sociological Review*, 43 (6): 889-908.

Long, J. Scott (1987) Problems and Prospects for Research on Sex Differences in the Scientific Career. In L.S. Dix (eds) *Women: Their Underrepresentation and Career Differentials in Science and Engineering* National Academy Press, 157-169.

Long, J. Scott (1992) Measure of Sex Differences in Scientific Productivity. *Social Forces,* 71: 159-178.

Long, J. Scott and Mary F. Fox (1995) Scientific Careers: Universalism and Particularism. *Annual Review of Sociology*, 21: 45-71

Long, J. Scott and R. McGinnis (1981) Organizational Context and Scientific Productivity. *American Sociological Review,* 46: 422-442.

Loo, Chalsa M (1985) Biliterate ballot controversy: language acquisition and cultural shift among immigrants. *International Migration Review.* 19: 493-515.

Lotka, A. J (1926) The Frequency Distribution of Scientific Productivity, *Journal of the Washington Academy of Science,* 16: 317-323.

Luukkonen, Terttu, R.J.W. Tijssen, O. Persson and G. Sivertsen (1993) The Measurement of International Scientific Collaboration, *Scientometrics*, 28 (1): 15-36.

Mahlck, Paula (2001) Mapping gender differences in scientific careers in social and bibliometric space, *Science Technology & Human Values,* 26 (2): 167-90.

Manrique, Cecilia G and Gabriel G. Manrique (1999) *The Multicultural or Immigrant Faculty in American Society.* Lewiston, The Edwin Mellen Press.

Martin, Philip L (2003) *Highly skilled labor migration: Sharing the benefits.* International Institute for Labour Studies. Geneva Switzerland, IILS Publications.

Matloff, Norman (1997) The role of immigrants in the U.S. computer industry, past and present. Workshop on the migration of scientists and engineers to the USA, 1997, Boston. USA.

Matloff, Norman (1998) *Debunking the Myth of a Desperate Software Labor Shortage,* Testimony to the U.S. House Judiciary Committee, Subcommittee on Immigration. April 21, 1998.

Meadows, A. J. and J.G. O'Connor (1971) Bibliographic Statistics as a Guide to Growth Points in Science. *Science Studies,* 1(1): 95-99.

Melin, G (2000) Pragmatism and self-organization Research collaboration on the individual level. *Research Policy,* 29: 31-40.

Meltzer, Bernard N. (1949) The Productivity of Social Scientists, *American Journal of Sociology,* 55 (1): 25-9.

Merton, Robert K (1949) Patterns of Influence: A Study of Interpersonal Influence of Communications Behavior in a Local Community. In Paul F. Lazarsfeld and Frank N. Stanton, *Communications Research,* New York.

Merton, Robert K (1968) The Matthew effect in science. *Science,* 159 (3870): 56-63.

Merton, Robert K (1973) The Normative Structure of Science, in Robert K. Merton (eds) *The Sociology of Science*. Chicago: University of Chicago, 267-278

Mervis, Jeffrey (1999) Cheap Labor Is Key to U.S. Research Productivity. *Science*, Sep 3, 1999: 1519-1521.

Mervis, Jeffrey (2004) Many Origins, One Destination. *Science* 304 (28 May 2004), 1277.

Mickelson, R. and M. Oliver (1991) The Demographic Fallacy of the Black Academic: Does Quality Rise to the Top? In *College in Black and White: African American Students in Predominantly White and in Historically Black Public Universities*, Walter Allen (eds), Albany, State University of New York Press.

Mincer, Jacob (1974) *Schooling, Experience, and Earnings.* New York, Columbia University Press.

Mitchell, J. and D. Rebne (1995) Nonlinear Effects of Teaching and Consulting on Academic Research Productivity. *Socio-Economic Planning Sciences,* 29(1): 47-57.

NAFSA (2003) *In America's Interest: Welcoming International Students.* Report of the Strategic Task Force on International Student Access, Association of International Educators.

Narin, Francis (1976) *Evaluative Bibliometrics: The Use of Publication and Citation Analysis in the Evaluation of Scientific Activity.* Cherry Hill, Computer Horizons.

Nakashima, Ellen and Alan Sipress (2002) Tighter U.S. Policy Leaves Foreign Students in Limbo Visas Delayed by Months for Thousands of Men From 26 Countries With Large Muslim Populations. *Washington Post.* Tuesday, September 24, 2002; Page A17.

National Academy of Engineering (1996) *Foreign participation in U.S. research and development: asset or liability?* Proctor P. Reid and Alan Schriesheim (eds), Committee on Foreign Participation in U.S. Research and Development, National Academy of Engineering, Washington, D.C. National Academy Press.

National Research Council (1987) *The New Engineering Research Centers: Purposes, Goals, and Expectations.* Cross-Disciplinary Engineering Research Committee, National Research Council, Washington DC: National Academy Press.

National Research Council (1995) *Research-Doctorate Programs in the United States Continuity and Change.* Washington, D.C: National Academy Press.

National Research Council (1998) *Trends in the early careers of life scientists.* Washington DC: National Academy Press.

National Research Council (1988) *Foreign and Foreign-born Engineers in the United States: Infusing Talent, Raising Issues*, Office of Scientific and Engineering Personnel (OSEP). Washington DC: National Academy Press.

National Research Council (1993) *National Collaboratories Applying Informational Technology for Scientific Research.* Washington, DC: National Academy Press.

National Science Board (2002) *Science and Engineering Indicators 2002.* Arlington, VA National Science Foundation (NSB 02-01).

National Science Board (2003) *The Science and Engineering Workforce Realizing America's Potential*. NSB 03-69, National Science Foundation.

National Science Board (2004) *Science and Engineering Indicators 2004.* Arlington, VA: National Science Foundation (NSB 04-1).

National Science Foundation (1996) *Immigrant Scientists, Engineers, and Technicians: 1993,* NSF, Washington, D.C.

National Science Foundation (1998) *Statistical Profiles of Foreign Doctoral Recipients in Science and Engineering: Plans to Stay in the United States.* An SRS Special Report. Division of Science Resources Studies. November 1998.

Niyekawa, Agnes M (1983) Biliteracy acquisition and its sociocultural effects. In *Asian and Pacific American Perspectives in Bilingual Education.* M. Chu-Chang (ed). Columbia University.

Norris, Julie T. (2004) *Restrictions on Research Awards: Troublesome Clauses.* A Report of the AAU/COGR Task Force. Association of American Universities, August 2004.

North, David S. (1995) *Soothing the establishment: The impact of foreign-born scientists and engineers on America.* University Press of America, Inc.

Onida, F. and F. Malerba (1989) R&D Cooperation between Industry, University, and Research Organizations in Europe. *Technovation*, 9(3): 131-191.

Ostry, S and Richard R. Nelson, *Techno-Nationalism and Techno-Globalism: Conflict and Cooperation,* Washington D.C.: The Brookings Institution, 1995.

Pao, Miranda Lee (1982) Collaboration in computational musicology. *Journal of the American Society for Information Science,* 33(1): 38-43.

Papanek, Hanna (1973) Men, women, and work: Reflections on the two-person career. In Joan Huber (eds), *Changing Women in a Changing Society.* Chicago: University of Chicago Press.

Park, Paula (2001) Managing the Scientific Multitudes, *The Scientists*, Oct 1, 2001, 15[19]:31.

Parker, Linda (1997) *The Engineering Research Centers (ERC) Program: An Assessment of Benefits and Outcomes.* Engineering Education and Centers Division, National Science Foundation, Arlington, Virginia.

Pelz, Donald C. and Frank M. Andrews (1966) *Scientists in Organizations: Productive Climate for Research and Development.* John Wiley and Sons, Inc, New York.

Peters, L and H.I. Fusfeld (1983) *Current US University-Industry Research Connections, in National Science Foundation, University-Industry Research Relationships.* NSF. Washington, D.C.

Pfeffer, Jeffrey and Nancy Langton (1993) The Effects of Wage Dispersion on Satisfaction, Productivity, and Working Collaboratively: Evidence from College and University Faculty. *Administrative Science Quarterly*, 38: 382-407.

Pravdic, N and Oluic-Vukovic, V (1986) Dual approach to multiple authorship in the study of collaborator / scientific output relationship. *Scientometrics*, 10: 259-280.

Presser, Stanley (1980) Collaboration and the Quality of Research. *Social Studies of Science*, 10(1): 95-101.

Price, D. J. and Beaver D (1966) Collaboration in an invisible college. *American Psychologist,* 21: 1011-1018.

Qin, J., F.W. Lancaster and B. Allen (1997) Types and Levels of Collaboration in Interdisciplinary Research in the Sciences, *Journal Of The American Society For Information Science,* 48 (10): 893-916.

Rebne, D. (1989) Faculty Consulting and Scientific Knowledge: A Traditional Univeristy-Industry Linkage. *Educational Administration Quarterly,* 25(4): 338-357.

Reskin, B (1977) Scientific productivity and the reward structure of science. *American Sociological Review.* 42 (3): 491-504.

Rodriguez, Roberto (1998) Home-grown scientists; national labs scramble to produce more U.S.-born scientists of color. *Black Issues in Higher Education* (Sept 17): 36-37.

Roessner, David (2000) *Outcomes and Impacts of the State/Industry-University Cooperative Research Centers (S/IUCRC) Program.* Science and Technology Policy Program, SRI International, Washington DC.

Rogers, Juan D. (2000) Theoretical Consideration of Collaboration in Scientific Research, In *Strategies for Competitiveness in Academic Research,* J. Scott Hauger and Celia McEnaney (eds), AAAS, Chapter 6.

Rosenwald, Michael (2003) Science + Security = Trouble. *Popular Science,* 262(2): 41-42

Salmon, Susan Snider (2004) keys to success: Employing foreign nationals. *NACE Journal*, 64(2): 6.

Sax, L. J., L.S. Hagedorn, M. Arredondo, and F. A. Dicrisi (2002) Faculty Research Productivity: Exploring the Role of Gender and Family-Related Factors. *Research in Higher Education,* 43(4): 423-446.

Saxenian, AnnaLee (1999) *Silicon Valley's New Immigrant Entrepreneurs.* Public Policy Institute of California; (September 1, 1999).

Saxenian, AnnaLee (2002) *Local and Global Networks of Immigrant Professsionals in Silicon Valley.* Public Policy Institute of California, San Francisco CA.

Sevier, E. Dale and A. Stephen Dahms (2002) The role of foreign worker scientists in the US biotechnology industry. *Nature Biotechnology,* 20: 955-956.

Seymour, E and N.M. Hewitt (1997) *Talking about leaving: Why undergraduates leaves the sciences.* Boulder, Co: Westview Press.

Shields, Michael A. and Stephen Wheatley Price (1999) The English Language Fluency and Occupational Success of Ethnic Minority Immigrant Men Living in English Metropolitan Areas. Mimeo.

Shin, Eui Hang and Kyung-Sup Chang (1988) Peripherization of Immigrant Professionals: Korean Physicians in the United States. *IMR,* 22: 609-626.

Shkolnikov, Vladimir D. (1994) *Scientific Bodies in Motion: The Domestic and International Consequences of the Current and Emergent Brain Drain from the Former USSR.* Project on Migration Within and From the Former Soviet Union, RAND.

Shkolnikov, Vladimir D. (1995) *Potential Energy: Emergent Emigration of Highlty Qualified Manpower from the Former Soviet Union.* Ph.D. Dissertation, RAND Graduate School (May 1995).

Shusterman, Carl (1991) Opening the Door for Immigrant Professionals. *Issues in Science and Technology,* Fall 1991.

Skolnikoff, Eugene B (1993) Knowledge Without Borders? Internationalization of the Research Universities. *Daedalus*, 122 (4): 225-252.

Song, Ha-Joong (1991) *Who Stays? Who Returns? The Choices of Korean Scientists and Engineers.* Ph.D. Dissertation, Harvard University (May 1991).

Stankiewicz, Rikard (1979) The Size and Age of Swedish Academic Research Groups and Their Scientific Performance. In *Scientific Productivity: The effectiveness of research groups in six countries.* Frank K. Andrews (ed). Cambridge University Press. Unesco.

Stephan, Paula E and Sharon G. Levin (1992) *Striking the Mother Lode in Science: The Importance of Age, Place, and Time.* Oxford University Press.

Stephan, Paula E and Sharon G. Levin. (2001) Exceptional contributions to US science by the foreign-born and foreign-educated. *Population Research and Policy Review,* 20: 59-79.

Stephan, P.E. Grant C. Black, James D. Adams, and Sharon G. Levin (2002) Survey of foreign recipients of U.S. Ph D's, *Science,* (March 22, 2002), 295: 2211-2212.

Stephan, Paula E and Sharon G. Levin (2003) Foreign Scholars in U.S. Science: Contributions and Costs. In *Science and the University*, Ronald Ehrenberg and Paula Stephan (eds). University of Wisconsin Press, forthcoming.

Subramanyam, K. (1983) Bibliometric studies of research collaboration: A review, *Journal of Information Science*, 6: 33-8.

Tainer, Evelina (1988) English language proficiency and the determination of earnings among foreign-born men. *Journal of Human Resources,* 23: 108-122.

Tang, Joyce (2000) *Doing engineering: The career attainment and mobility of Caucasian, Black, and Asian-American engineers.* Rowman & Littlefield Publishers, Inc.

Thiederman, Sondra (1989) Overcoming Cultural and Language Barriers. *PM. Public Management,* 71(1): 19

Tien, Flora F. and Robert T. Blackburn (1996) Faculty Rank System, Research Motivation, and Faculty Research Productivity, *Journal of Higher Education,* 67 (1): 2-22.

Vogel, Gretchen (1999) Working Conditions: A Day in the Life of a Topflight Lab. *Science,* 285: 1531-1532.

Vroom, V.H. (1964) *Work and Motivation.* New York, Wiley.

Waldinger, Roger, Mehdi Bozorgmehr, Nelson Lim, and Lucila Finkel (1998) *In search of the glass ceiling: the career trajectories of immigrants and native-born engineers.* The Lewis Center for Regional Policy Studies. Working Paper #28. January 1998.

Wanner, Richard A., Lionel S. Lewis and David I. Gregorio (1981) Research productivity in Academia: A Comparative Study of the Sciences, Social Sciences and Humanities, *Sociology of Education,* 54 (4): 238-53.

Wegener, Bernd (1991) Job Mobility and Social Ties: Social Resources, Prior Job, and Status Attainment. *American Sociological Review,* 56 (1): 60 – 71.

Wermuth, Dieter and Nanny Wermuth (1975) Some Determinants of the Migration of Professional Manpower. *Demography*, 12 (4): 615-628

Wilson, Robin (2004) Settles for Less. *The Chronicle of Higher Education,* October 8, 2004

Woo, Deborah (1994) *The Glass Ceiling and Asian Americans.* A Research Monograph. US Department of Labor. Glass Ceiling Commission. July 1994.

Xie, Yu and Kimerlee A. Shauman (1998) Sex Differences in Research Productivity: New Evidence about an Old Puzzle. *American Sociological Review,* 63: 847-870.

Xie, Yu and Kimberlee A. Shauman (2003) *Women in Science: Career Processes and Outcomes.* Harvard University Press.

Zhao, Yilu (2004) The Visa Trap. *New York Times*, Section 4A, P32, Jan 18, 2004

Zuckerman, Harriet (1967) Nobel Laureates in Science: Patterns of Productivity, Collaboration, and Authorship. *American Sociological Review*, 32 (3): 391-403.

Zuckerman, Harriet (1972) Age, Aging, and Age Structure in Science. In *The Sociology of Science: Theoretical and Empirical Investigations.* Robert K. Merton. The University of Chicago Press.

Zuckerman, Harriet and Robert Merton (1971) Patterns of Evaluation in Science: Institutionalization, Structure and Functions of the Referee System. *Minerva,* 9:66-100.

VITA

Sooho Lee was born in South Korea in 1964. He holds a Master of Public Administration degree (2000) from Iowa State University. In 1988 he earned his bachelor's degree in political science from Kyungpook National University in Daegu, Korea. In 2000 he enrolled in the doctoral program in School of Public Policy at the Georgia Institute of Technology where he is majoring in science and technology policy, public management, and research methods. During his doctoral program, he has been working for several S&T policy research projects with Dr. Barry Bozeman, Dr. Juan Rogers, and Dr. Monica Gaughan, and for outsourcing and partnership projects with Dr Gordon Kingsley.